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CONTROL

SYSTEMS · INSTRUMENTATION · DATA PROCESSING · ENGINEERING · APPLICATIONS

A TECHNICAL JOURNAL FOR DESIGNERS AND USERS OF ELECTRICAL, ELECTRONIC, HYDRAULIC, MECHANICAL AND PNEUMATIC CONTROL SYSTEMS AND INSTRUMENTATION

VOL 4 NO 33 MARCH 1961

SPECIAL FEATURES

REGULAR FEATURES

LOOKING FOR A JOB? Control *carries the best jobs in instrument and control engineering.* **SEE PAGE 185 AND ONWARDS**

RM ROWSE MUIR PUBLICATIONS LIMITED, LONDON, ENGLAND

LOOKING AHEAD

Unless otherwise indicated, all events take place in London. B.C.A.C., British Conference on Automation and Computation. B.C.S., British Computer Society. Brit.I.R.E., British Institution of Radio Engineers. I.C.E., Institution of Civil Engineers. I.Chem.E., Institution of Chemical Engineers. I.E.E., Institution of Electrical Engineers. I.Mech.E., Institution of Mechanical Engineers. I.Prod.E., Institution of Production Engineers. I.S.A., Instrument Society of America. R.Ae.S., Royal Aeronautical Society. S.B.A.C., Society of British Aircraft Constructors. S.I.T., Society of Instrument Technology.

MONDAY 13 MARCH
A one-day informal discussion on cybernetics. I.Mech.E.

WEDNESDAY 15 MARCH
Burst slug detection data display at Bradwell by J. O. Ross. 7 p.m. S.I.T.
Initial experience on the use of a digital computor for burst slug detection by J. L. W. Churchill. 7 p.m. S.I.T.
Airborne servo system for throttle control by D. W. Thomasson. 7 p.m. School of Management Studies, Bristol. Details: W. C. Henshaw, School of Management Studies, Unity St, Bristol, 1.

THURSDAY 16 MARCH
Recent developments in industrial electronics by E. Metcalf. 7.15 p.m. Derby and District College of Technology, Kedleston Rd, Derby. S.I.T.

MONDAY 20—FRIDAY 24 MARCH
2nd conference on *X-ray analytical methods.* Sponsored by Research and Control Instruments in conjunction with Dept of Geology, Manchester University. Details: Conference Secretary, Research and Control Instruments Ltd, 207 Kings Cross Rd, London, W.C.1.

TUESDAY 21 MARCH
Discussion on *Self-adaptive control systems.* Opened by J. H. Westcott, J. L. Douce, P. E. W. Grensted and P. H. Hammond. 5.30 p.m. I.E.E.

TUESDAY 21—SATURDAY 25 MARCH
10th Electrical Engineers Exhibition, Earls Court. Details: G. J. Lundin, Electrical Engineers Exhibition, 6 Museum House, 25 Museum St, W.C.1.

WEDNESDAY 22 MARCH
Some impressions of instrumentation in the U.S.S.R. by E. N. Martin. 7.30 p.m. Cleveland Scientific and Technical Institute, Middlesbrough. S.I.T.
Discussion on *The future of high speed storage systems.* 5.30 p.m. Brit.I.R.E.

THURSDAY 23 MARCH
Electromagnetic flowmeters by Leo M. Bennett. 7 p.m. Lecture Theatre, Administration Bldg, Associated Ethyl Co. Ltd, Oil Sites Rd, Ellesmere Port, Wirral. S.I.T.

MONDAY 27—FRIDAY 31 MARCH
3rd Symposium on *Temperature—its measurement and control in science and industry.* Veteran's Memoral Hall and Deshler-Hilton Hotel, Columbus, Ohio, U.S.A. Sponsors: I.S.A., American Institute of Physics, National Bureau of Standards. Details: Meetings Manager, I.S.A., 313 Sixth Av., Pittsburgh, 22, Pa, U.S.A.

TUESDAY 28 MARCH
Automatic optimization by P. E. W. Grensted. 5 p.m. S.I.T.
The development of an optimizing controller by P. F. Sutherby. 7 p.m. S.I.T.

WEDNESDAY 29 MARCH
One-day conference on *Lower costs and higher quality by instruments and control.* College of Technology, Gosta Green, Birmingham. S.I.T. Details: D. Smith, I.C.I. Ltd, Metals Divn, Kynoch Wks, Witton, Birmingham, 6.
Symposium on *Electronic instrumentation for nuclear power stations.* 3 p.m. Brit.I.R.E.

FRIDAY 7 APRIL
One-day meeting on *Aids to training in automatic control*, at Northampton College, London, E.C.1. Registration: C. D. M. Johnston, 75 Herons Wood, Harlow, Essex.

WEDNESDAY 12 APRIL
A symposium on *Materials of construction* at Birmingham University. Details: T. R. Bott, Chemical Engineering Dept, The University, Birmingham, 15. I.Chem.E.

THURSDAY 13 APRIL
The Graham Clark lecture: *Resources, human and material, of the Commonwealth*, by H.R.H. The Duke of Edinburgh. I.C.E.

MONDAY 17—WEDNESDAY 19 APRIL
7th National U.S.A. Symposium on *Instrumental methods of analysis.* Shamrock-Hilton Hotel, Houston, Texas, U.S.A. Details: Meetings Manager, I.S.A., 313 Sixth Av., Pittsburgh, 22, Pa, U.S.A.

TUESDAY 18—WEDNESDAY 19 APRIL
Science and industry—the problem of communication. Brangwyn Hall, Swansea. Registration: D.S.I.R. Liaison Officer for Wales, Block II, Government Bldgs, Gabalfa, Cardiff.

WEDNESDAY 19 APRIL
The design, application and selection of automatic control valves by P. Stone. 7 p.m. The Conference Room, Roadway House, Oxford St, Newcastle upon Tyne, 1. S.I.T.
Electronic telephone exchanges by T. H. Flowers. 7 p.m. S.I.T.

THURSDAY 20 APRIL
One-day symposium on *Air traffic control.* R.Ae.S., 4 Hamilton Place, W.1.

THURSDAY 20 APRIL—THURSDAY 4 MAY
Engineering, Marine, Welding and Nuclear Energy Exhibition, Olympia.

TUESDAY 25 APRIL
Instrumentation in the iron and steel industry by A. H. Pople. 7 p.m. S.I.T.

WEDNESDAY 26 APRIL
Symposium on *Electronic counting techniques.* 6.30 p.m. Brit. I.R.E.

SUNDAY 30 APRIL—THURSDAY 4 MAY
7th National aero-space instrumentation symposium. Adolphus Hotel, Dallas, Texas., Details: W. J. Gabriel, Convair Divn, General Dynamics Corp., Ft Worth, Texas, U.S.A.

WEDNESDAY 3 MAY
Symposium on *Computer control of air traffic.* 5.30 p.m. Brit. I.R.E.

WEDNESDAY 3—THURSDAY 4 MAY
Railway modernization. A conference organized jointly by I.C.E., I.Mech.E., and I.E.E. Details: I.C.E.

WEDNESDAY 3—SATURDAY 13 MAY
British Columbia International Trade Fair, Exhibition Park, Vancouver, Canada.

MONDAY 8—WEDNESDAY 10 MAY
4th National I.S.A. Power Instrumentation Symposium. La Salle Hotel, Chicago, Ill., U.S.A. Details: Meetings Manager, I.S.A., 313 Sixth Av., Pittsburgh, 22, Pa, U.S.A.

TUESDAY 9—WEDNESDAY 17 MAY
International Exhibition of Measurement, Control, Regulation and Automation (Mesucora) and 58th Exhibition of French Physical Society. C.N.I.T., Paris. Secrétariat Général, 40, rue du Colisée, Paris, 8e, France.

WEDNESDAY 10—FRIDAY 12 MAY
Pulp and Paper Instrumentation Symposium. Northland Hotel, Green Bay, Wisc., U.S.A. Sponsors: I.S.A. and T.A.P.P.I. Details: Meetings Manager, I.S.A., 313 Sixth Av., Pittsburgh, 22, Pa, U.S.A.
An international conference on *Materials handling.* Southport. Details: Institute of Materials Handling, 69 Cannon St, London, E.C.4.

FRIDAY 19 MAY—SUNDAY 4 JUNE
British Trade Fair, Moscow. Details: Industrial and Trade Fairs Ltd, Russell St, London, W.C.2.

MONDAY 22—WEDNESDAY 24 MAY
10th National Telemetering Conference, Hotel Morrison, Chicago, Ill., U.S.A., Sponsors: I.S.A., A.I.E.E., A.R.S., I.A.S., I.R.E. Details: Meetings Manager, I.S.A., 313 Sixth Av., Pittsburgh, 22, Pa, U.S.A.

TUESDAY 30 MAY—FRIDAY 2 JUNE
Radio and Electronic Component Show, Olympia. Details: Industrial Exhibitions Ltd, 9 Argyll St, W.1.

LOOKING FURTHER AHEAD

TUESDAY 6—THURSDAY 8 JUNE
I.S.A. Summer Instrument-Automation Conference and Exhibition, Royal York Hotel and Queen Elizabeth Hall, Toronto, Ont., Canada. Details: Wm H. Kushnick, I.S.A., 313 Sixth Av., Pittsburgh, 22, Pa, U.S.A.

MONDAY 12—THURSDAY 15 JUNE
British Electrical Power Convention: *Electricity in the prosperity and welfare of the nation.* Details: Electrical Development Association, 2 Savoy Hill, W.C.2.

MONDAY 12—SATURDAY 17 JUNE
Conference on *Components and materials used in electronic engineering.* Central Hall, Westminster, S.W.1. I.E.E.

TUESDAY 13—FRIDAY 16 JUNE
3rd Biennial International Gas Chromatography Symposium, Kellogg Center, Michigan State University, East Lansing, Mich., U.S.A. Details: Meetings Manager, I.S.A., 313 Sixth Av., Pittsburgh, 22, Pa, U.S.A.

THURSDAY 15—FRIDAY 16 JUNE
Two open days at Bisra's Sheffield Laboratories. Details: D. U. Hunt, B.I.S.R.A., 11 Park Lane, London, W.1.

MONDAY 19—FRIDAY 23 JUNE
6th International Instrument Show. 4 Tilney St, Park Lane, W.1. Sponsors: B. & K. Laboratories.

TUESDAY 27—FRIDAY 30 JUNE
A conference on *The social and economic effects of automation*, sponsored by members of the B.C.A.C. Applications for tickets to The British Institute of Management, 80 Fetter Lane, E.C.4.

WEDNESDAY 4—THURSDAY 12 OCTOBER
Second Electronic Computer Exhibition and Symposium, London. Details: Mrs S. S. Elliott, 64 Cannon St, E.C.4.

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CONTROL

Bigger and better

OPTIMUM, SAYS THE OXFORD DICTIONARY, means best or most favourable: a simple-sounding definition, which helps no one who seeks what it describes. To discover rational measures of what is 'best' or 'most favourable' has been perhaps the underlying philosophical quest of every thinking man in the history of thought. That is partly why the engineering fraternity has fastened on the word 'optimum'. An imported and neutral term is used to exclude metaphysical, ethical and emotional kinds of evaluation, so that engineers can start off firmly with the best objective intentions. Unfortunately, borrowing a word from biology has not helped as much as one would like in narrowing down the scope of enquiry. One is still confronted by an embarrassing variety of criteria.

Cost is an obvious standard, but it is seldom a simple and single number of currency units. Not only does cost have many components, but each of these components is also liable to fluctuations and long-term trends which blur the calculations and may make them too vague to bother with. Sheer volume of production is sometimes the most important consideration, and this gives other answers again: every engineer knows that the fuel mixture which gives him most economical motoring is not the same as the mixture for maximum power. With particular products the quality (measured by dimensional accuracy, chemical composition, consistency, distribution, or what you will), may be the primary interest. To take yet another example, in certain processes the vital factor might be the time taken to restore normality after a disturbance: and so on. Such possibilities as these are the relatively easy ones, because in each case there is a predominant consideration: cost, output, quality, time, etc. In practice the aims of an organization are likely to be a peculiar complex of factors like these, without enough weighting to suggest effective simplifying assumptions. The lot of the plant designer can therefore be a tough one, and he may be driven to rely on an indefinable mingling of inspired hunch, assimilated experience, native genius—and reasonable luck. Given the luck, design on this basis admittedly often leads to working systems that can subsequently be developed and improved to a highly satisfactory extent.

Now, if it is as difficult as all this to decide in quantitative terms what one is really after, plainly a great deal of careful thought is needed before an automaton (which must be told in rigid language exactly what it has to do) can be expected to 'optimize' the operation of any complicated system. Many systems can of course be reasonably broken down into cells for which, relative to the immediate environment, there is a pre-assignable criterion of optimality: but then one comes up against the old problem of interaction. As the cells are recombined and one considers the system that they construct, one asks what the cells must do to optimize not only their individual behaviour but also the performance of the whole system. It is now more difficult to formulate a criterion of optimality.

Given peace on earth, the processes of production in our society ought undoubtedly to become more integrated and automatized, and party-political manifestos will in time give place to computer programs. With the progress of this evolution the fundamental facts of the human condition are bound to make life harder for those criterion-seekers who work on the bigger systems; for the larger and more intricately woven is the system one studies, the more perilously does one move in among the kinds of question that engineers have avoided from the outset—ethical, philosophical and political problems to which men have no unique and easily verifiable solution.

This may seem a gloomy prospect and a sterile subject for discussion, but we think it healthy to remind ourselves occasionally that the uncharted is infinitely greater than that which we are able to map. Engineers do not throw up their hands in cosmic despair at this, like mystics subsiding into delitescence after contemplating the immensities of astronomy. Men do have a realm in which they can help themselves, and that realm has not reached anything like the limit of its possible expansion. Having opened the window a crack to feel the chilling gale from the outer world, practical folk can shut it again and return to tend their little fire: the blaze is nowhere near its optimum yet.

In next month's issue of *Control* we shall publish a very interesting contribution by A. P. Roberts of Imperial College. In this article the author will introduce and explain to readers a selection of the different kinds of self-optimization that have been proposed. Readers may also like to have their attention drawn to two meetings on the subject this month, at the I.E.E. on the 21st and the S.I.T. on the 28th. Fuller details will be found on p. 4.

VIEWPOINT

N. A. Dudley, Lucas Professor of Engineering Production at Birmingham University, says that designers of control systems should understand both . . .

PEOPLE AND PROCESSES

' Control ', says Professor J. C. West, ' is the study of the performance of interlinked and related devices, whether designed as a completely automatic feedback system, or with the loop closed inherently by human action,' and, as such, is ' the very essence of engineering '.* As one moves from the control of an individual operation or process to the overall control of an entire manufacturing unit—that is, from the elemental devices and systems to the production system of which they form an integral part—the engineering contribution tends to diminish, while economic and psychological considerations assume relatively greater importance. The design of automatic control mechanisms has attracted more attention and progressed much faster than the design of control systems for entire manufacturing units, which appear to stimulate interest only when the completely automatic factory becomes technically and economically feasible.

There are many situations in which the elimination of the human factor is a desirable objective, but recent research has shown that, even in so limited a task as the design of an automatic control-unit for a sensitive drilling-machine, there is much to be learned from a scientific analysis of the skills used by the operator. Where, as in this case, attempts to mechanize an operation are less effective than one might expect, it may be advantageous to simulate the performance of the human operator. This is only possible, however, when the signals to which the operator responds have been identified, and the nature of his responses determined precisely.

Another investigation has revealed not only the extraordinary range of performance of instruments used to measure surface finish, but the considerable effect of human skill and judgement in their use. The engineer should not, even in the simplest control situation, underestimate the complexity and subtlety of ' human action ', and should acquaint himself with the contributions of experimental psychologists and physiologists in this field of ergonomics. Control engineering is the meeting place of a number of disciplines. The control of a manufacturing unit, conceived as a single process or system, involves many more disciplines, some less tangible and less predictable than those with which the engineer is most familiar.

So far as control engineering is concerned, it may well be, as Professor West argues, that at undergraduate level it can in part be assimilated in the established schools of engineering, with additional courses for specialists at undergraduate and postgraduate levels. So far as the control of a production unit is concerned, there is much to be said for separate—though necessarily postgraduate—teaching and research departments. The Advisory Council on Scientific Policy has said that ' there should be a greater effort in research into industrial economics in order to provide management with control techniques of appropriate precision '. This is true, but unless control systems are designed by those who have an intimate knowledge, in terms of people and processes, of what has to be controlled, optimum systems are unlikely to result. The attitudes of those engaged in production are often more important than their capacities, and unless a complex manufacturing unit is seen as a single process, in which technical efficiency may not always be compatible with efficient or even economic production, the concept of the automatic self-regulating control of production will be barren.

N. A. Dudley

* Viewpoint, December 1960

LETTERS to the EDITOR

Gas Sampling

SIR: I have been following your "nuclear" series with interest, and have been struck by an apparent divergence between the views of two of your contributors. Mr. Tindale, in your issue for December 1960, described a co-ordinate gas-sampling system, and the month after Dr. Taylor referred to an apparently less sophisticated system. I wonder whether your authors would care to explain the relative merits of these two designs?

If there are n channels, it would appear that on the co-ordinate system it is necessary to lead $2\sqrt{(n)}$ pipes away from the pressure vessel, while the other system requires n pipes to pierce the vessel wall. Since $2\sqrt{(n)}/n < 1$ for $n > 4$, it would seem on the face of it that there is a practical case for the co-ordinate system when there are more than 4 channels, for then fewer holes are needed in the pressure vessel.

Woolwich J. K. S. DEAN

● *Dr. Taylor writes: 'Mr. Dean is correct in his statement that Mr. Tindale and I have put forward slightly divergent views. There are, however, good reasons for our particular points of view. The system described in my article was that used at Calder Hall and no more advanced system has so far received the approval of C.E.G.B. and has been put into operational use.*

'The next stage designs reduced pipework and hole exits by moving selector valves onto or inside the pressure vessel. There are snags in a matrix-type co-ordinate system such as blow variations and blockage of pipes which may still demand the bringing out of all pipes before matrix connection. Nevertheless for the simpler problem of the Advanced Gas Cooled Reactor with the smaller number of fuel element channels the matrix-type co-ordinate system has been adopted by the U.K.A.E.A., the actual system being that devised by Plessey Nucleonics Ltd, and described recently by Hough. Assuming that more channels may be parallelled, current opinion favours continuous monitoring of the group with a special arrangement for individual channel selection. This latter system has been discussed in the article already referred to by Hough and in the recent Annual Survey of "Nucleonic Instrumentation"* in Nuclear Power.†

'* Hough, G. V., "Review of Recent Developments in the Design of Burst Fuel Element Detection Systems for Power Reactors", Instruments and Measurements Conference, Stockholm, September 1960. (See also account of this conference in *Nuclear Power*, November 1960 pp. 104-108.)
† Taylor, D., "Nuclear Instrumentation", *Nuclear Power*, January 1961, pp. 77, 78, 79'.

● *Mr. Tindale writes: 'In reply to your correspondent Mr. Dean, I would state that there is no real divergence between the views of Dr. Taylor and myself regarding a co-ordinate gas-sampling system. As far as my example is concerned the valve developed by Elliott Brothers (London) Ltd, and its application to a co-ordinate system as described, is a glimpse into the future. Dr. Taylor's article on the other hand described a system which had been installed.*

'From my description, of course, the number of pipes taken through the pressure vessel would be $2\sqrt{(n)}$ but there would be an upper limit to this determined by the dilution of the gases which must contain a detectable level of fission products in the event of a rupture of the fuel can.'—EDITOR.

Control's importance

SIR: During a recent trip to England I happened to buy at a railway bookstall the November 1960 issue of your journal. I had not been aware of its existence before, but I was very much pleased with its contents and especially with Mr. J. Foody's article on controlling v.t.o.l. aircraft at transition speeds, although (or perhaps because) I am not a specialist on aircraft control. In my opinion, this and some other articles have very well struck the best combination of theory and practice.

Therefore I wish that many engineers will carefully read your journal, which should give them new ideas and perspectives to apply to their daily practice.

Zürich, Switzerland JEAN THOMA

● *We do not as a rule publish our 'unsolicited testimonials', but we think Dr Thoma's letter is worth treating as an exception. It is a well-deserved compliment to Mr Foody, and it implies that 'control' is a subject of general importance to engineers. We heartily agree.*—EDITOR.

Space-vehicle attitude

SIR: I was interested to read Mr Scher's reply to my letter* and to find that he had no main disagreement with the proposal. However, I think he must be under some slight misapprehension regarding the feed to the jacks. The jacks would have to be attached through some elastic constraint to the vehicle structure so that the precessional movements can be imparted to it.

The connection would be at the centre of the jack cylinder which should not move with respect to the vehicle structure.

Two opposed piston rods from each cylinder would be attached respectively to opposing gyroscopic gimbals. It will be seen that apart from some slight movement to allow a degree of spring anchor take-up, no departure of the gyroscopic system from that of the vehicle need occur since the precessional movements required for the gyroscopes, as a result of the applied precessional torques, would be satisfied by the vehicle's movement in space. Flexible pipes, therefore, to the jack would be all that would be required, and no fluid slip rings would be necessary. Command signals would be given to the hydraulic relays to supply the pressure to the jacks as necessary. J. TINDALE

Elliott Bros (London) Ltd

* 'Letters' last month, p. 84.—EDITOR

Who's copying?

SIR: In the issue of *Control* dated December 1960 you published, on pages 121 and 122, a description of a Russian development for the measurement of the conductivity of liquids.

We wish to draw your attention to the fact that the use of this development in this country may constitute an infringement of our Patent No. 695058.

Fielden Electronics Ltd L. TREMLETT

Fig. 1 Model of finished structure

Half the area of a football field,
the dish of the new Australian instrument
has to be pointed with great precision .
regardless of wind and weather.
The completed installation
will be the second-largest steerable
radio-telescope in the world,
only slightly smaller than Jodrell Bank
and much more accurately controlled

Controlling the big Australian radio-telescope

by J. ROTHWELL
A.E.I. Ltd

THE RADIO PHYSICS LABORATORY OF THE COMMONWEALTH Scientific and Industrial Research Organization (C.S.I.R.O.), amongst the most advanced in the world in radio astronomy, decided recently to construct a large radio-telescope. As is of course well known, Britain already has such a telescope at Jodrell Bank. This, at a latitude of 53°N, covers the northern hemisphere, but not vital parts of the southern hemisphere. A corresponding instrument in Australia will complete the coverage. It is being erected at a latitude of 33°S near the town of Parkes, some 200 miles west of Sydney, New South Wales. This particular site has been chosen because it fulfils the paramount requirement for a low level of electrical noise, thus allowing very weak signals from distant stars to be received without undue interference. When complete, it will be the second-largest steerable radio-telescope in the world to become operational and will have cost around £600,000.

Some impression of the magnitude of the project may be obtained if one considers that the area of the dish is approximately half that of a football field. The overall height of the structure is about 190 ft and the total weight of the moving parts 850 tons, 650 tons of which is on the altitude bearings.

The basic structural design was carried out by the consulting engineers, Freeman Fox & Partners, of London. The main contractors, Maschinenfabrik Augsburg-Nürnberg A.G., (M.A.N.), Gustavsburg, West Germany, are making the 210 ft diameter paraboloidal dish and supporting rotating turret structure.

The sub-contract for astronomical equipment, including the control desk, master equatorial and error detector units, has been given to Askania Werke of Berlin. A.E.I. Ltd are responsible for the accurate positioning of the dish with respect to the error detector, and are designing and manufacturing the servo-control system and all electrical apparatus, including cabling, lighting and communications equipment.

CONTROL SYSTEM

The control system provides three methods of operation:

a Drive for the reflecting dish about an axis parallel with the earth's polar axis at the desired angles of declination (equatorial co-ordinates), at a speed such that the effect of the earth's rotation is cancelled when pointing at a distant star (sidereal rate)

b Automatic scanning of different sectors of the sky

c Manual control of the telescope about a vertical and horizontal axis (altazimuth co-ordinates) for preliminary target acquisition, stowing purposes, and following local objects

The operational range of the telescope is 0–60° from zenith in the altitude motion and ±225° about 70°E in the azimuth motion. The maximum speeds of the telescope are 24° per minute in the azimuth motion and 15° per minute in the altitude motion. This will permit ten times the sidereal rate to be used in equatorial co-ordinates, even when passing close to the zenith.

The average positioning error must not exceed 15″ of arc, and the fluctuating component must not be more than 15″ above this when the average wind speed is 20 mile/h. The total pointing error between the actual radio beam and the indicated position of the nominal axis must be less than 2′ in a 20-mile/h wind and 1′ in a 10-mile/h wind.

The equipment is designed to operate in ambient temperatures varying between 35°F and 110°F.

Equatorial-altazimuth conversion

Mounting of the reflector on polar axes would have simplified the control problem for the main system, but mechanical and structural difficulties ruled out this method and the alternative method of mounting the reflector on altazimuth axes and converting the demanded position from equatorial co-ordinates to altazimuth co-ordinates has been adopted. This conversion is carried

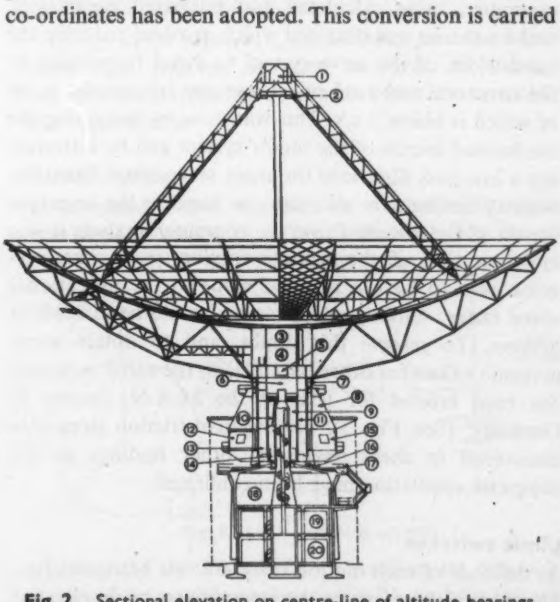

Fig. 2 Sectional elevation on centre-line of altitude bearings. 1 Aerial cabin. 2 Aerial platform. 3 Vertex room. 4 Hub room. 5 Error detector. 6 Master equatorial room. 7 Altitude bearing. 8 Turret. 9 Junction room. 10 Ladder. 11 Turret access tower. 12 Motor room. 13 Counterweight. 14 Cable room. 15 Turret radio room. 16 Roller. 17 Roller track. 18 Control room. 19 Tower radio room. 20 Store.

out automatically by causing the reflector to follow a mirror which is driven at sidereal rate about a polar axis by a small ' master equatorial unit '. The drive for the mirror is velodyne-controlled, the speed being de-

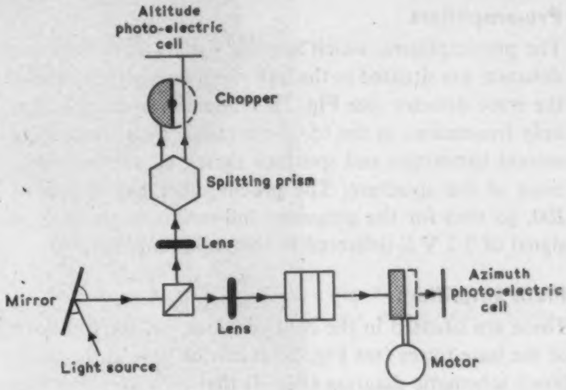

Fig. 3 Scheme of error detector

termined by a crystal-controlled oscillator. The deflexion of a beam of light transmitted from the hub of the dish and reflected from the mirror is converted in the ' error detector unit ' into electrical error signals for the altitude and azimuth drives. This system has advantages over the use of computers for co-ordinate conversion in that it eliminates various sources of error by enclosing them within the loop of the control system, and also it avoids need for data transmission over a distance before producing the actuating error signal (*1*).

Error detector

The error detector unit is at the base of the hub immediately above the altitude axis, as can be seen in Fig. 2. The deflexion of the reflected beam of light is split into two error signals for the altitude and azimuth drives by the following means (see Fig. 3). The reflected beam is first split by a half-silvered mirror into two components, each of which is further divided into two parallel beams by means of splitting prisms. These parallel beams are of equal intensity under zero-error conditions. Consider only one of the splitting prisms; if an error causes the light to be deflected away from the edge of the prism, then one of the parallel beams emerging from the prism will be increased in intensity and the other will be decreased. A rotating light chopper, with its axis between the two beams and rotating at 70 rev/s, breaks up the two beams, which fall on a photo-electric cell. The result is that, under zero-error conditions, when the two parallel beams are of equal intensity, the output of the photo-electric cell is virtually constant, whereas when an error is introduced a 70-c/s component is obtained whose amplitude depends directly on the magnitude of the error. The systems for altitude and azimuth errors are identical, except that the two prisms have their axes at right angles, i.e. an error causing light to be deflected along the edge of one prism and producing no output

causes light to be deflected away from the edge of the other prism and thus produces an error signal.

The order of signal obtained from the error detector is 2 mV/″.

Pre-amplifiers

The pre-amplifiers, which amplify signals from the error detector, are situated in the hub room immediately above the error detector (see Fig. 2). These are tuned to accept only frequencies in the 65/75-c/s range, thus eliminating second harmonics and spurious signals caused by vibrations of the structure. The pre-amplifier has a gain of 200, so that for the proposed full-torque angle of 8″ a signal of 3·2 V is delivered to the main amplifier.

Main amplifiers

These are situated in the control room, i.e. the top floor of the base tower (see Fig. 2). It can be seen in the basic block schematic diagram (Fig. 4) that each amplifier has two input channels, each consisting of a phase-sensitive rectifier, a process stage, and a driver stage. One of these channels receives its signals from the error detector *via* the tuned pre-amplifier for the equatorial control, and

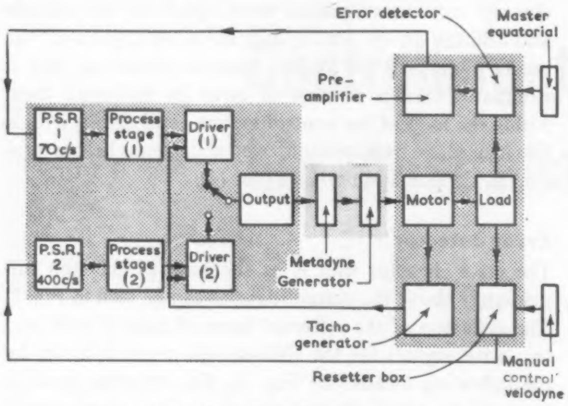

Fig. 4 Block diagram of basic servo-system

the other channel receives a signal from a velodyne-driven synchro resetter, whose associated transmitter is mechanically coupled to the load of the motion concerned, for altazimuth control. The two driver stages feed a common output stage, and change-over between the two modes of control is effected by cutting off one driver stage or the other. Facilities are provided for injecting stabilizing feedback signals between the process stage and the driver stage of each channel. The d.c. stages of the amplifiers, i.e. those stages after the phase-sensitive rectifier, are all push-pull, and to minimize the possibility of single-sided failures, each pair of valves has its heaters wired in series, so that if the heater fails in one valve of a push-pull pair, both valves will cease to function, thus retaining symmetry.

Rotary amplifiers

A three-stage rotary amplifier, consisting of a metadyne generator whose output excites the field of a d.c. generator, has its control winding excited by the output of the main amplifier. Overall current-feedback is used from the generator armature current to the primary control axis of the metadyne in order to reduce the equivalent overall time constant of the machine set to the order of 50 ms. The armature of the d.c. generator feeds the two servo-motor armatures, connected in series to ensure load-sharing.

Drive motors

The two azimuth motors, which develop a combined stalled torque of 1300 ton ft at the load, drive two of four rollers mounted on bogies under the turret structure, which run on a 37 ft 6 in diameter steel track fixed to the roof of the concrete base tower. This method goes some way towards reducing the backlash in the final drive. In the altitude motion the two motors, which together develop a stalled torque of 2750 ton ft at the load, drive racks on the counterweights of the elevating structure. This can be clearly seen in Fig. 5. The effect of backlash here is minimized by causing the counterweights to bias the structure towards a point beyond the zenith under all conditions, so that the load is always held at one side of the backlash.

Control problems

A servo-system, with a sufficiently fast response to correct short-time disturbances of the structure in gusty wind, presents a complex stability problem. The complexity arises from the interaction with structural resonances. The system was simulated on the A.E.I. analogue computer, using calculated and estimated parameters, and a solution was obtained which involved reducing the band-width of the servo-system to avoid responding to the structural and mechanical resonant frequencies, none of which is below 2 c/s. This was done by increasing the mechanical inertia of the motor system and by introducing a low-pass filter into the main servo-loop. Transient velocity feedback is also used to increase the apparent inertia of the system. From the computer analysis it was apparent that, if the azimuth friction/speed characteristics were to have a negative slope in the operational speed range, stability and accuracy would be difficult to achieve. To resolve this doubt, and to obtain more accurate values for other parameters, the turret structure has been erected for tests at the M.A.N. factory in Germany. (See Figs 5). No negative friction slope was discovered in these tests, and other findings in the computer simulation have been confirmed.

Limit switches

At the ends of each motion there are two limit-switches. The first of these causes the structure to be decelerated to a safe speed, and the second causes the mechanical brakes to be applied and the motor fields to be de-energized. (No mechanical stops are fitted at the limits of movement.)

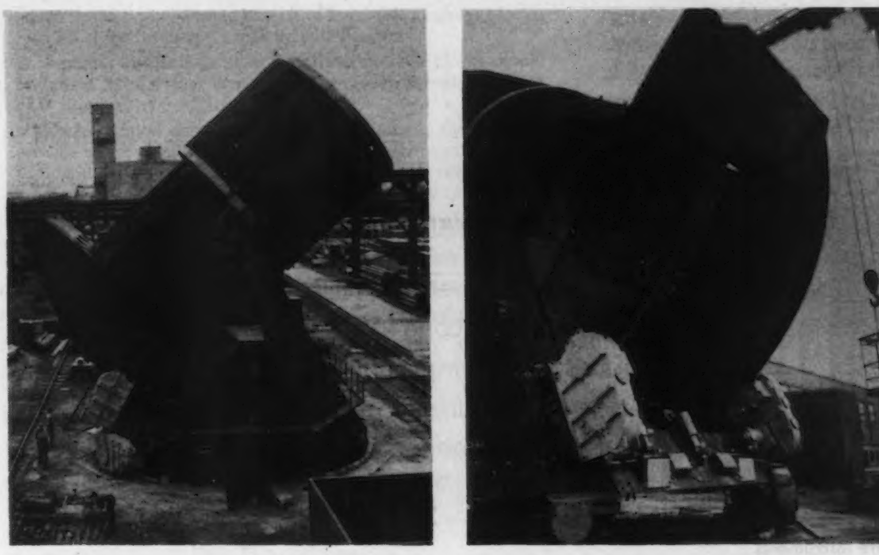

Fig. 5 Turret and hub structure during trial erection

Because of the overlap in the range of movement in azimuth (total movement 450°) another switch is fitted which renders one pair or the other of the azimuth limit switches inactive (see Fig. 6). This switch is mounted in the neutral position, and as the turret passes this position the switch changes over and short-circuits the limit switches which would be first encountered by the turret, and at the same time short circuits are removed from the other pair of limit switches. Since the limit switches are normally closed and their associated relays normally energized, short-circuiting the limit switches prevents the associated relays from being de-energized, and thus makes the limit switches ineffective.

As an extra safeguard, in addition to conventional track limit switches operated by cams, all the limit switches are duplicated by others which are coupled to the gear-boxes.

Safety devices

It is intended that the dish be stowed when average wind-speed exceeds 20 mile/h, and also when the telescope is not in use. Provision is therefore made for

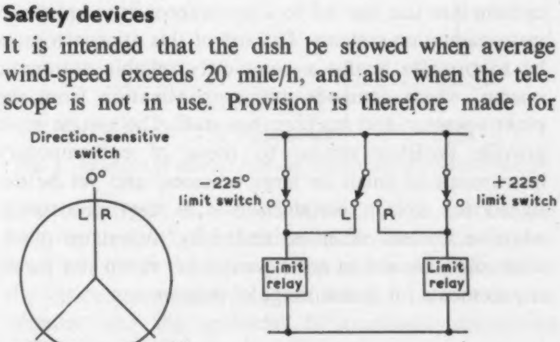

Fig. 6 Limit switching scheme

stowing the dish in the zenith position by means of a motor-driven locking bolt (see Fig. 5), and for the whole of the turret structure to be raised on eight hydraulic jacks (two per bogie) to relieve the pressure on the rollers when the telescope is not in use, and to avoid damage in high wind. Some of these jacks can be clearly seen in Fig. 5. Emergency stop buttons and safety interlock keys are put in eight places on the structure. These will shut the supplies down and apply the brakes when operated. A further safety device is an overspeed trip in the altitude motion. A relay is energized from a tacho-generator in one of the motors and preset to operate when the altitude drive reaches a speed of 17°/min. Operation of this relay causes the brakes to be applied.

Radio interference

Because of the extremely sensitive receivers in use on the telescope and on other telescopes on the same site, very stringent precautions have had to be taken to prevent radiation of any radio noise from any of the control equipment. For this and other reasons, slip-rings could not be used for transferring power, signals, etc. from the fixed part of the structure to the moving part and *vice versa*. Instead, flexible cables are used in an elaborate cable-twisting system specially designed for this project. This carries 24 multi-core cables for control, with facilities for twelve special r.f. cables for use with radio equipment. All relays and contactors are housed in compartments sealed against r.f. leakage. The main probable sources of interference are the metadyne/generator set, the servo-motors, and their interconnecting cables. The metadyne/generator set is used in a sealed metal room. The servo-motors are all fitted with screening cans, and the cables between them are run in conduit whose joints are sealed against electrical leakage. All other cables have an overall screening braid and special glands are used for terminating these braids.

Reference

1. Wallis, Barnes *et al*: *Improvement in telescope mounting* (Brit. Pat. App. No. 29248/1955. Full spec. 11 Jan. 1957).

Acknowledgement

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PART 1—System design

Miniature instrumentation has arrived, and there is plenty of scope for advanced electronic techniques. This comprehensive article discusses operation and requirements, and describes how some of the components should be designed

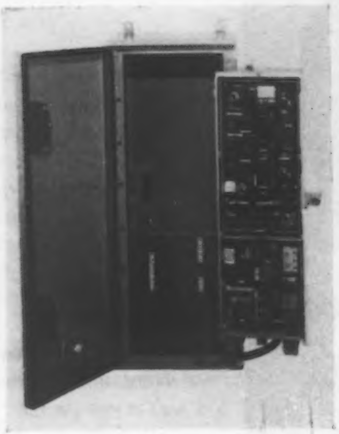


Fig. 1 Control panel using miniature instruments

Electronics in industrial process control

by **G. B. MARSON** B.Sc., A.Inst.P. *and* **I. C. HUTCHEON** M.A., A.M.I.Mech.E., A.M.I.E.E.
George Kent Ltd

THE LAST DECADE HAS WITNESSED A STEADY BUT UNspectacular introduction of electronic techniques into industrial instrumentation. In the main the effect of this change has been to 'electrify' certain parts of existing instruments, for example in the replacement of the mechanical servo-mechanism by an electronic amplifier and servo-motor in self-balancing potentiometers. Sensitivity and speed of response have thus been greatly improved, resulting in measuring instruments with laboratory standards of accuracy and speed, but with the ruggedness and reliability required for industrial process use. Control action using such instruments is generally catered for by providing an electronic or pneumatic controller inside or close to the measuring instrument. The input to the control unit is in many cases the displacement of the recording or indicating mechanism. This system may be necessary when the controller is pneumatic and the primary signal electric, but if the control unit is itself electrical it is clearly desirable to seek an entirely passive control system, and eliminate any mechanical link from the control loop.

The type of system described above has come about because in the majority of industries the application of automatic control has arrived considerably later than the development of the corresponding measuring techniques. Control units have thus been evolved mainly as appendages to measuring instruments. During the coming decade, if the promises of automation are fulfilled, the primary object of process instrumentation will be control. Indication and recording will be required only for off-normal conditions or subsequent quality analysis. In a fully automatic plant, indicators and recorders will eventually become redundant. This prospect, together with the marked increase in the number of instruments coming into use, has led to a new approach to industrial instrumentation systems. The aim of this approach must be to provide finally a completely reliable automatic system, which demands minimum attention from the plant operator and maintenance staff. The system must provide facilities similar to those of contemporary instruments in small or large schemes, and yet be designed for use in conjunction with data processing, adaptive control schemes, and fully automatic plant. With such an aim in mind we can lay down the prime requirements for a new range of instruments.

Prime requirements

1 In view of the increasing number of instruments to be used on each plant, the physical size of individual units both on and off the control panel should be reduced as far as practicable.

2 In the interests of reliability, control loops should contain only those units required for control. Facilities such as recording, alarms etc., should always be optional additions and arranged in parallel rather than in cascade with controlling units.

3 To ease the work of application and specification in complex

schemes, the system should consist of separable modular blocks, each block performing a single definite function.

4 To permit complete flexibility, all these modular blocks should be linked by a similar electrical transmission signal (e.g. 3–15 or 0–10 mA).

5 Where manual control facilities are required, these should provide where possible for instantaneous transfer from automatic to manual operation and *vice versa*, without necessity for rebalancing operations on the part of the operator.

A simple control scheme built up on these lines is shown in Fig. 2, and this may be contrasted with the more conventional system in Fig. 3. It will be seen that the complexity of the control loop is greatly reduced, and indicating and recording instruments may easily be added or removed.

Range of units required

The functional units required for a process control system of this type fall into five general categories:

1 Transducers and signal converters to convert each process variable into the standard transmission signal

2 Control units with adjustable gain and frequency response, having both input and output in the form of the standard transmission signal

3 Recorders and indicators accepting the standard transmission signal

4 Regulators accepting the standard transmission signal and producing physical movement or control of electrical power

5 Ancillaries, such as integrators, alarm and trip units, summators and multipliers etc.

Units in the first two categories are those in which modern electronic techniques may be used to greatest advantage, and these will be described briefly below.

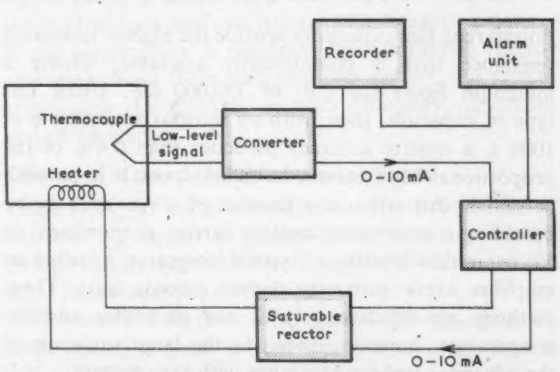


Fig. 2 Example of electric furnace control using modular system

The second part of the article will deal in more detail with the design and operation of the electronic circuits involved. In the third part of the article we shall discuss the various types of regulator suitable for use with such systems, and the problems of automatic starting-up and auto/manual switching.

Signal converters

Primary transducers for modern electronic control systems are unlikely to differ greatly from those used for the past ten or twenty years. The physical variables to be measured include temperature, pressure, flow, displacement, pH and conductivity; transducers for these variables produce outputs in the form of a low-level electrical signal, a force, or a displacement. The purpose of the signal converters must then be to convert these outputs into the standard transmission signal, rather than into the displacement required for indicating or recording in existing instruments.

Low-level direct-current signals (from the thermocouples, pH electrodes, etc.) are dealt with almost exclusively by feedback amplifiers arranged as shown in

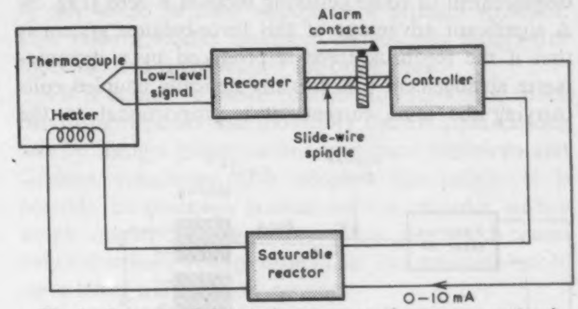


Fig. 3 Example of electric furnace control using conventional recorder-controller

Fig. 4, in which the input voltage is balanced against the voltage developed across the feedback resistor by the transmitted current. This arrangement requires no reference voltage source, as would a potentiometric instrument, and the conversion accuracy (except where a suppressed zero is used) depends only on the gain and drift of the amplifier and the accuracy of the feedback resistor. For thermocouple measurements, the amplifier voltage drift must not exceed a few microvolts if an accuracy of about $\pm 0{\cdot}25$ degC is to be achieved.

Alternating voltage outputs are produced by electromagnetic flowmeters, and bridges for resistance thermometry, conductivity measurements etc. In all these cases the measured variable is represented by an a.c. ratio rather than a single alternating voltage, and signal conversion with a completely passive device is more difficult than with a self-balancing electromechanical instrument. One approach is to replace the conventional potentiometer with a thermistor potentiometer of the kind to be described in the second part of this article; this thermistor potentiometer may be supplied with both a.c. and d.c., and it can be used both to balance the input a.c. ratio signal and to produce a d.c. output.

Turning now to converters with non-electrical inputs, we find that these may be either essentially open-loop

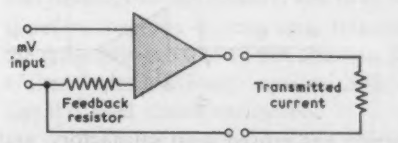


Fig. 4 Arrangement of feedback amplifier for voltage measurement

or feedback devices. Typical of the former kind are those based on the linear differential transformer; the input in this case is a displacement, which may itself be the variable to be measured, or may have been produced for example from an absolute pressure *via* a bellows or

diaphragm. The differential transformer output is, again, an a.c. ratio which may be dealt with as described above. Alternatively, the supply to the differential transformer may be stabilized and the output demodulated and converted to the appropriate transmission current by a feedback amplifier.

The alternative approach to pressure or force measurement is to balance the input with an electromagnetic force whose value is automatically adjusted until the displacement of some detecting pick-off is zero (Fig. 5). A significant advantage of this force-balance system is that if the feedback force is produced by a dynamometer arrangement (i.e. two magnetically coupled coils carrying the same current), it is proportional to the

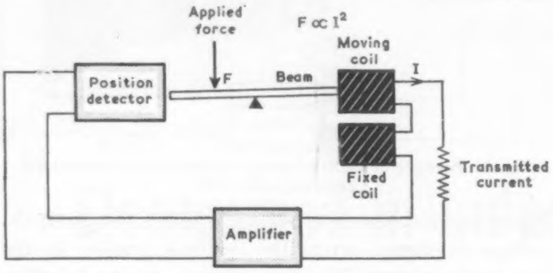


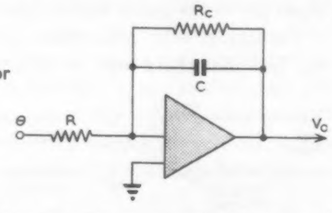
Fig. 5 Force-balance system for pressure measurement

square of the current. This current, if used as the transmission signal, is then proportional to the square root of the input pressure, and in this way provides a linear flow-signal.

Controllers

Electronic control units developed during the past few years have reproduced very closely the characteristics of their pneumatic equivalents. In the more advanced industries, quantitative data on process and plant characteristics are becoming more readily available, and in such cases it may be possible to specify the correct control-system frequency-response for each particular case. However, in the great majority of process control applications no such data are available, and the response of controllers for these applications must be easily and widely adjustable on site. For this purpose the conventional three-term controller with adjustable proportional, integral

Fig. 6 Miller integrator



and derivative action has proved most satisfactory, and this type of electronic controller will be required for some years to come.

At first sight the electronic controller would appear to have advantages in sensitivity and speed of response over its pneumatic counterpart. In practice, however, the improvement in speed of response is often nullified by the time lag in the final regulator, and the electronic three-term controller is also subject to fundamental limitations which may restrict its accuracy. These limitations arise in the provision of drift-free integral action, corresponding to the necessity, in the pneumatic case, of constructing a leak-proof integral chamber.

The problem may be explained by reference to the typical Miller integrator shown in Fig. 6. The object of the integrator in a three-term controller is to enable the output of the unit to take up any value (within the range of its output signal) when the control deviation is zero. Referring to the figure, and assuming for the moment an amplifier of infinite negative forward gain, a finite output voltage V_o will always cause a small current V_o/R_c to flow towards the amplifier input through the leakage resistance R_c of the capacitor. V_o will drift steadily downwards owing to this leakage input, unless the latter is balanced by a corresponding current flowing through R, due to a control offset θ; i.e. for the steady state

$$V_o/R_c = \theta/R$$

If the input proportional band is V_p volts, then the corresponding maximum input current is $i_m = V_p/R$, and this would cause C to charge to a potential V_o in a time $T_I = CV_o/i_m$, T_I being the integral action time. Thus the control error θ, as a fraction of the proportional band is

$$\frac{\theta}{V_p} = \frac{V_oR/R_c}{RCV_o/T_I} = \frac{T_I}{CR_c}$$

Polystyrene film capacitors provide the highest insulation resistance that is commercially available, having a minimum figure for CR_c of 250,000 ΩF. Using this type of capacitor, then, with an integral action time of 1000 s, a control accuracy of better than 0·4% of the proportional band cannot be relied upon. It is possible to reduce this error in a number of ways, such as by providing a small compensating current proportional to V_o, or, in the 'bootstrap' type of integrator, by using an amplifier whose gain very slightly exceeds unity. These methods are effective only at one particular ambient temperature, however, owing to the large variation of the capacitor leakage resistance with temperature.

Electronic process controllers are thus unlikely to provide any immediate improvements in either control response or steady-state accuracy, except by the elimination of pneumatic transmission lags, and the design of such units should be aimed at providing maximum reliability, ease of operation, and freedom from saturation effects from the derivative or integral action. The requirements of maximum reliability and miniaturization imply that thermionic valves must be replaced if possible by solid-state devices such as transistors or magnetic amplifiers, and this immediately introduces a further problem in the design of the integrator. The input current drift of the integrator amplifier should clearly be of the same order or less than the capacitor leakage current

referred to above. The latter may be typically 10^{-9} A, and although an equally low input current may be obtained in electrometer valves, its achievement with solid-state devices requires special techniques which will be discussed in the second part of this article.

On the other hand, electronic methods permit the development of completely passive control units with no moving parts, giving great flexibility in characteristics, position of operating controls, etc. Considerable

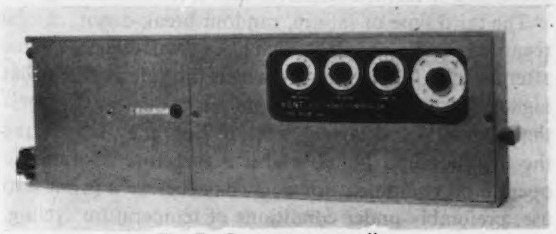


Fig. 7 Converter-controller

simplification is possible in the provision of bumpless auto-manual switching, and cascade control schemes are easily arranged. Control units suitable for a modular system must have the standard transmission signal as both input and output, as shown in Fig. 2. A special case occurs in the control of any variable using a primary transducer with an electrical output (e.g. a thermocouple). In this case, to simplify the control loop, it may be possible to use a controller such as that shown in Fig. 7. This instrument will operate direct from the thermocouple signal, enabling one to move the signal converter outside the control loop and use it only as a measuring device. If the temperature is regulated by a saturable reactor operating direct from the controller output, the system approaches the ultimate in both reliability, simplicity and performance.

Choice of a standard transmission signal

There is as yet no international standard for electrical transmission signals in process control systems (*1*) although it is likely that a British standard will be decided upon in the near future.

The use of a current rather than a voltage signal enables one to connect several receivers or controllers in series, and obviates the effect of line resistance. Devices requiring a voltage input may easily be provided for by including a shunt resistor in the transmission line

D.C. signals have overwhelming advantages over a.c. in transmission, since only the resistance of the circuit need be considered, and such factors as line impedance, pick-up from external fields etc., may be ignored. In certain types of measurement, such as magnetic flow, conductivity etc., the use of a.c. circuits is very desirable, but, as explained previously, the measured value is then generally represented by an a.c. ratio rather than an actual voltage or current, and by employing suitable circuitry a d.c. transmission current may be derived with the advantages stated above.

The choice of the actual range of the d.c. transmission signal is governed to a large extent by the increasing use of transistors. The signal range should be small enough to be controlled without difficulty by typical transistor circuits, preferably without using large heat sinks, i.e. below about 20 mA, and large enough to be measured with simple, directly coupled amplifiers or direct-deflexion indicators, without accuracy-loss from amplifier drift or instrument errors. This necessitates a current exceeding 1 mA, preferably exceeding 5 mA. This suggests that 10 mA would be most suitable as a primary standard. This value is readily measured by portable meters (for checking) and is convenient for calculation.

If it is desired to use direct-deflexion recorders, which require more power than indicators, there is quite a strong case for using a larger current, and some American and German companies have adopted this policy. It is possible, however, to precede such a recorder with a simple amplifier of stable and accurate gain, which causes only a fractional voltage drop in the line, enabling one to use a lower transmission current.

The question of a true zero (e.g. 0 to 10 mA) or a live zero (e.g. 2 to 10 mA) is a little more vexed (*2*). With electric current, as opposed to pneumatic pressure, it is relatively easy to obtain zero or slightly negative signals. It is also possible to add or remove a small electrical bias signal using a simple reference source. Thus both systems are feasible, as is conversion from one to the other. The live zero signal has a particular advantage in permitting some converters to use the same two wires for both power supply and signal transmission, as shown in Fig. 8. On the other hand, in schemes where signals require to be multiplied or linearized, or square roots taken (e.g. for flow, temperature etc.) it is essential

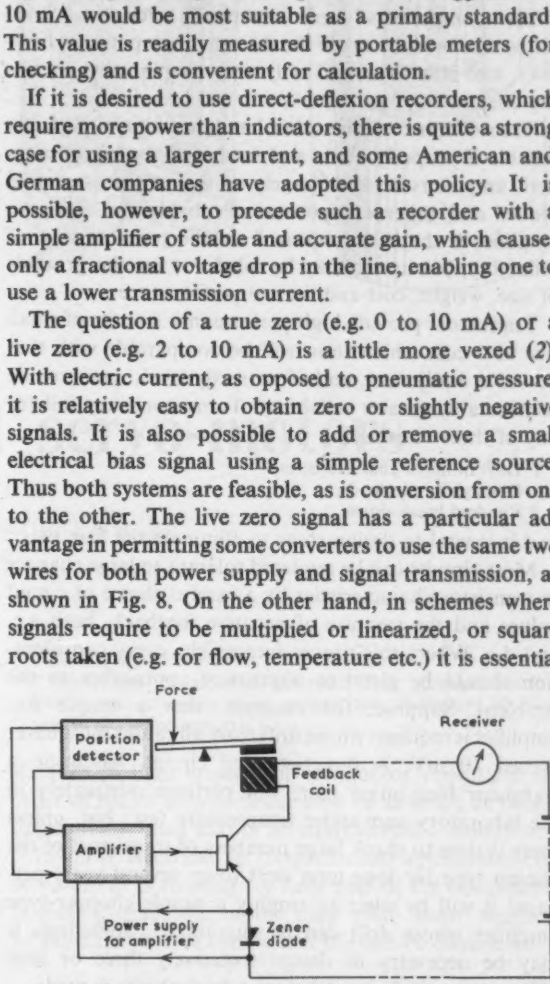


Fig. 8 Force-balance converter with power supply at receiver

for zero current to represent zero measured-variable. The tendency in this country, and in Europe generally, is therefore towards a true zero transmission signal in the range between 0 to 10 mA and 0 to 20 mA, but in the United States a live zero equal to 20% of the maximum signal is used almost exclusively.

Reliability considerations

The need for extreme reliability in electronic control equipment is evident, and one authority now specifies that all new equipment should be designed for a life of ten years: but statements of this sort are only a very general

guide unless qualified by information as to the percentage of equipments which must survive the stated period, and to fix ideas it is suggested that a practical target for equipments designed during the next few years is that not less than 50% should survive ten years of continuous operation without a single failure.

Services 'reliable' thermionic valves have an inoperative failure rate of about 1% per year, hence a five-valve equipment would just meet the target if all other components were completely reliable. Some allowance must be made for the other components, however, and it is clear that only very simple valve circuits are adequate.

Transductors, on the other hand, are almost perfectly reliable if properly made and used, and the life of magnetic amplifiers depends largely on that of the associated diodes and other components. Probably the magnetic amplifier is the best solution from the point of view of reliability, but its use may be ruled out on the grounds of size, weight, cost and limited performance.

Transistors provide high-performance circuits of small size at a cost which soon will be comparable with that of valve equipment, and, if correctly used, can provide considerably greater reliability. Transistors may fail for any of three reasons:—

1 Drift in major characteristics,
2 Damage by overloads,
3 Random break-down,

and it is vital to design so as to eliminate the first two.

Most circuits can be rendered tolerant to large changes in transistor characteristics by a careful choice of circuit values and the free use of negative feedback, both a.c. and d.c. Where this proves impossible, every consideration should be given to alternative approaches to the problem. Suppose, for example, that a simple d.c. amplifier is required whose drift from all causes must never exceed 10 mV. A direct-coupled circuit, based on a transistor long-tailed pair, will perform adequately in the laboratory and under temperature test: but, unless there is time to check large numbers of transistors of the chosen type for long-term drift (over several years perhaps) it will be wiser to employ a simple chopper-type amplifier whose drift can be guaranteed. Sometimes it may be necessary to design tentatively three or four different types of circuit before a final choice is made.

Semiconductors are inherently much more susceptible to damage by transient over-loads than are valves, and the same applies to some of the miniature components (e.g. tantalum capacitors) which are used in conjunction with them. Very careful attention must therefore be paid to protecting the circuits from external effects, and to ensuring that the circuits themselves generate no damaging transients, either during continuous operation or when switched on and off. The use of novel circuits developed around semiconductor devices, and frequently employing switching techniques, makes the latter a considerable task. Development effort is most efficiently used by designing as few types of circuit as possible, and using each to the greatest possible extent after exhaustive tests and field trials. Careless servicing may well cause more damage than was originally present, and detailed fault-finding in the field is not very practicable. The best solution appears to be to design equipment in modular form with a sufficient number of prominent tests points to enable the service engineer to isolate and replace the faulty sub-unit. When a circuit has proved its reliability over several years, potting will be advantageous in protecting it from mechanical and electrical damage.

The third type of failure, random break-down, can be regarded as a failure rate which has a small constant value after an initial period during which the rate is somewhat higher. Tests by transistor manufacturers (*3*) suggest that a small percentage of weak devices may fail during the first hundred hours, and it is therefore desirable to operate all equipment for a few days before it is put into use, preferably under conditions of temperature cycling.

After this initial period, the sustained inoperative failure rate for good modern semiconductor devices, tested at high ambient temperatures, appears to be between about 0·2 and 0·4% per year. The field experience of users of transistor equipment (*4*), however, suggests that under more temperate conditions the inoperative failure rate improves to about 0·1% per year. Thus if two transistors replace one valve, transistor equipment will be five times as reliable as similar equipment using 'reliable' valves, and, if all other components were perfectly reliable, the target specification would be met by a fifty-device equipment.

The choice of other components must be based on a detailed knowledge of their internal construction, specification and probable reliability. Electrolytic capacitors, for example, should be made of tantalum or highly pure aluminium, even though the latter may be double the size of cheaper types.

Carbon-film resistors should not be used where solid types will do, and wire-wound resistors should not employ wire thinner than 46 s.w.g. Potentiometers should, when possible, have resistors connected between each end and the wiper, to minimize the effect of a possible open circuit.

The list of individual facts is endless, but a few principles are clear: the production of highly reliable equipment is a co-operative enterprise, involving:

1 System planning for maximum simplicity
2 Careful design of tolerant circuits in modular construction. Protection from internal and external causes of overload
3 Choice of highest-quality components of the correct type
4 Careful manufacture and inspection
5 Rigorous type-testing and field trials
6 A prolonged test-run for all equipment before use
7 Use of minimum number of different designs

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The second part of this article follows next month.

PART I

How to estimate quickly the performance of a range of small servo-motors, so as to select the best for the job

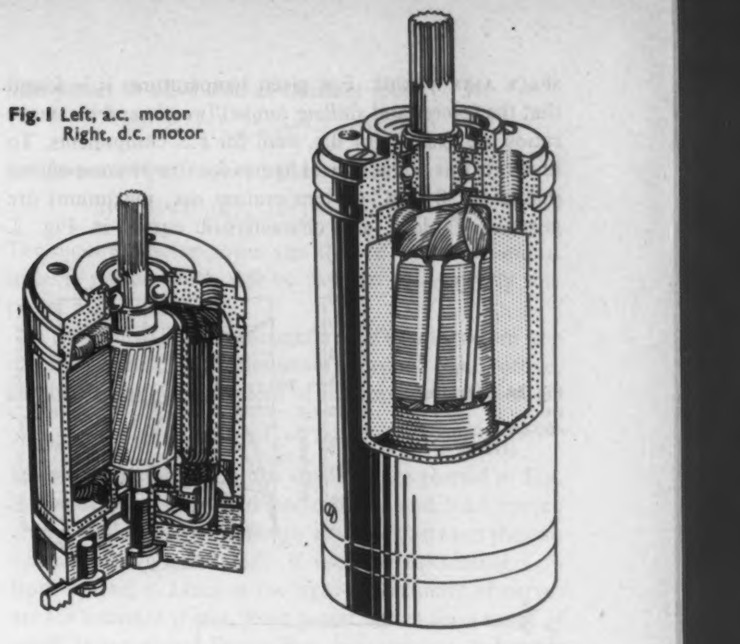

Fig. 1 Left, a.c. motor
Right, d.c. motor

Selecting small servo-motors

by **T. B. WEARDEN** B.Sc.(Tech.), A.M.I.E.E.
Vactric (Control Equipment) Ltd

WHEN A SERVO-MOTOR LOAD-DRIVE SYSTEM IS TO BE designed, many factors may influence the choice of the servo-motor. These factors are summarized below and practical design techniques are discussed. We shall refer mainly to the smaller International-Frame-Size motors (examples are shown in Fig. 1) but the principles considered may be extended to include cases where the powers, torques and inertias are larger.

A.C. and d.c. systems

In many applications the choice of an a.c. or d.c. system is immediately suggested by the power supplies available. For example, modern aircraft employ a.c. systems at 400 c/s; an industrial process control system will probably be most conveniently powered by a.c. at 50 c/s; a portable instrument for field use may be battery-operated and a d.c. system would then be suggested. However, the choice may also be influenced by other conditions which we shall now discuss. These conditions should be considered, where applicable, before a final decision is made.

COMPONENT LIFE. With present design techniques the life of a small a.c. servo-motor of given size is inherently longer than that of an equivalent d.c. type run under the same conditions. There are two main reasons for the greater deterioration rate of the d.c. component:

1 Limitations of brush life,
2 Dissipation of armature-generated heat through bearings (this is proportionally much greater than dissipation of rotor heat in a.c. servo-motors).

Because of these aspects of d.c. motor operation, the order of life of an a.c. motor may be as much as twenty times greater than that of an equivalent d.c. component.

In most electrical servo-mechanism applications the servo-motor is running for only part of the equipment's operating time; the motor duty cycle must therefore be estimated before component life can be considered.

TABLE I

Comparison of characteristics for a.c. and d.c. servo-motors, size-11

PARAMETER	UNITS	A.C. MOTORS 400 c/s SIZE-11	D.C. MOTOR SIZE-11	RATIO OF D.C./A.C. VALUES
Max. power output	W	1·0	6·1	6·1
Stalling torque	gf cm	42	300	7·1
Weight	gf	110	145	1·3
Power/weight	W/gf	0·009	0·042	4·6
Power/diameter	W/in*	0·9	5·6	6·1
Stalling torque/weight	gf cm/gf	0·38	2·07	5·4
Stalling torque/diameter	gf cm/in*	38·1	273	7·1

* The diameter is shown in inches rather than centimetres to conform with International-Frame-Size standards.

SPACE AND WEIGHT. For given temperatures it is found that the (*power* and *stalling torque*)/(*weight* and *diameter*) ratios are greater for d.c. than for a.c. components. To illustrate this point, typical figures for size-11 components (based on 30 degC of temperature rise, maximum) are given in Table I, and characteristic curves in Fig. 2.

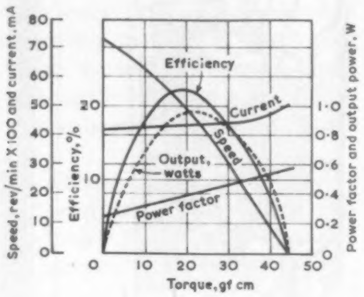

Fig. 2a Characteristics of size-11 400-c/s a.c. motor (115 V)

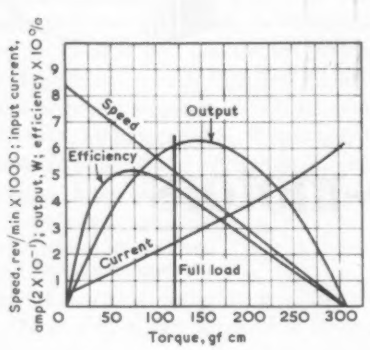

Fig. 2b Characteristics of size-11 d.c. motor (28 V)

(It should be noted from these characteristic curves that the d.c. motor will be overloaded if it is permanently stalled, whereas the lower rating of the a.c. component permits operation when stalled.)

ALTITUDE. The brush life of small d.c. motors is affected adversely by operation at high altitude (or under other conditions of low pressure). Generally it may be said that this effect becomes serious at altitudes of the order 45,000 ft to 50,000 ft, and it is therefore preferable to use an a.c. system where a life of more than a few hundred hours at high altitude is required.

ECONOMICS. When small a.c. and d.c. servo-motors are compared on a basis of power output, stalling torque or physical size, the trend is for d.c. permanent-magnet-field motors to be less expensive than a.c. or d.c. wound-field components, for given performance parameters and standard of construction.

Temperatures and servo-motor rating

The range of ambient temperatures to be encountered should be considered when selecting a servo-motor. At very low temperatures there may be difficulties with bearing lubricants, and stiction will be high owing to increased lubricant viscosity unless a special low-temperature grease is employed. At high ambient temperatures higher-grade winding-insulation materials may be needed as well as special lubricants, and the motor manufacturer should be consulted.

The class of winding insulation required is indicated by:

$$\text{Total motor temperature} = \text{Ambient temperature} + \text{Motor temperature rise}$$

(This is a simplified equation and does not take account of any hot spots in the motor).

In many small motors the parameters *peak power output* and *stalling torque* are limited by the motor's permitted temperature rise rather than by saturation of the iron or other effects. (In many cases manufacturers' figures are quoted for a maximum rise of 30 degC under specified heat-sink conditions.) It is therefore possible (if ambient temperature and duty cycle are favourable) to increase the values of the peak power output and stalling torque parameters by overrating the windings. There are two cases:

i Mean rated motor input power not exceeded; for example a relatively high current pulse might be passed through the control winding of a servo-motor, to overcome initial load stiction and give high load acceleration, in a fast-response low-duty-cycle system.

ii Mean rated motor input power exceeded; for example if the precautions discussed below are taken (to prevent deterioration of winding insulation through overheating and over-voltaging), the rated power output of a motor might be continuously exceeded by applying a control voltage higher than that for which the winding is designed.

When overrating techniques are used the following limitations and precautions must be carefully observed:

1 Maximum steady and surge voltages must be limited to prevent danger of insulation break-down. For this reason low-voltage control windings (e.g. 10–0–10 V, designed for transistor drive) are more suitable for overrating than high-voltage windings (e.g. 57·5–0–57·5 V designed for valve drive).

2 When the rated control-winding current is exceeded, linearity will fall off as the iron approaches saturation, and this should be investigated before deciding on the percentage overrating that may be usefully employed.

3 If the mean input power is to be increased above the rated value then the excess heat must be considered. The alternatives in this case are:

either: allow the motor temperature to rise, and raise the class of winding insulation, if necessary, to prevent danger of insulation break-down during the estimated component life,

or: maintain the rated motor temperature by providing additional heat-sink facilities, preferably with forced cooling.

Design approach

When the most suitable form of servo-motor drive has been considered in general terms, it is then necessary to select a suitable component from the range of types available.

Two load performance parameters have to be considered for preliminary selection. These are:

Maximum load running power
Load acceleration required

In some applications for small servo-motors it is found that one of these load parameters is predominant, and it is possible to optimize the system design parameters (particularly gear ratio); but in many cases a compromise is necessary. In the following discussion the theoretical

NOMENCLATURE

Torque (gf cm)

T_M = Motor output torque
$T_{M(\text{stall})}$ = Motor stalling torque

Speed (rad/s)

ω_M = Angular velocity of motor
ω_L = Angular velocity of load

Acceleration (rad/s²)

α_M = Angular acceleration of motor
α_L = Angular acceleration of load

Inertia (g cm²)

I_M = Motor inertia
I_L = Load inertia

Power (W)

W_M = Motor output power
W_L = Load driving power

Other motor parameters

$$\psi_M = \frac{(T_{M(\text{stall})}\, g)^2}{I_M} \times 10^{-7} \text{ W/s}$$

Efficiency

η = Gear-head torque efficiency

Gear ratio

N = Gear-head ratio, where $N > 1$ for step-down ratio

Constants

$K_{L(n)}$ = Generalized load running torque constant, when $T_{L(\beta)} = \Sigma K_{L(n)}\omega_L^n$
g = Gravitational acceleration (cm/s²)

Symbols such as ω_L', T_M' etc. indicate a defined or particular value of the generalized parameter.

aspects of both bases for motor selection are considered and practical design curves are presented which are applicable to International-Frame-Size motors up to size-18. With the help of these curves, motors suitable for a particular application can quickly be listed; final selection will then depend on the conditions of the system being designed.

The dynamic characteristics of an electrical servo-mechanism drive may be adjusted by the many techniques applicable to feedback systems, but in order that these techniques may be effective it is essential first to select a motor capable of meeting the extremes of performance, at start and full speed.

Load power

If the full required load-speed is to be achieved, the motor must be able to supply the power required.

In a previous article (*1*) it was seen that the running-load-torque components (where each component is proportional to a different power of load speed) may be expressed in the generalized form:

$$T_{L(\beta)} = \Sigma K_{L(n)}\omega_L^n \text{ gf cm}$$

and if (as is often the case) one load-torque component is predominant, the load torque is:

$$T_L = K_{L(n)}\omega_L^n \text{ gf cm}$$

then power to drive load at constant speed ω_L' is:

$$W_L' = K_{L(n)}(\omega_L')^{(n+1)} \times 10^{-4} \text{ W}$$

and power output required from motor is:

$$W_M' = (1/\eta)K_{L(n)}(\omega_L')^{(n+1)} \times 10^{-4} \text{ W}.$$

The required motor-power can thus be calculated and a suitable motor which will be capable of supplying this power may be selected.

A case which is often encountered in small servo-motor drives is that of a predominant constant load torque, i.e. load torque independent of load speed. In this case:

$$W_M' = (1/\eta)T_L\omega_L' \times 10^{-4} \text{ W}.$$

Design curves based on this equation are plotted in Fig. 3. Load speed is plotted horizontally and load torque on the vertical axis. The family of curves between the two vertical axes, T_L and T_L/η, is used for calculating T_L/η from T_L and η. Lines in the right-hand family of curves are for constant power. Peak power curves for a range of small International-Frame-Size servo-motors, rated for a maximum 30-degC temperature-rise under standard heat-sink conditions, are shown.

The procedure for selecting a servo-motor using these curves is:

1 Plot vertical for η.
2 Plot horizontal at point of intersection with appropriate curve for T_L.
3 Minimum motor-operating-power point is then at intersection with vertical for load speed.
4 In general, any motor whose power characteristic lies above this point will be capable of driving the load at the required maximum speed.

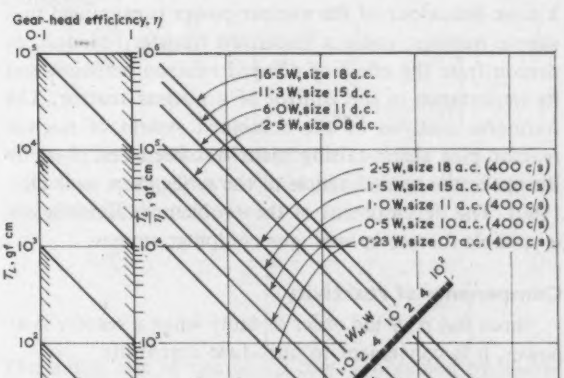

Fig. 3 Servo-motor selection on the basis of maximum power requirements

More generally, the curves in Fig. 3 may be used in any application where the maximum load speed and torque at that speed are specified.

Calculation of the correct gear ratio to achieve the desired load speed, when a suitable motor has been selected, has been discussed previously (*1*).

To be continued

Transient behaviour computed, assuming that the steam-raising side (including circulation system) always holds a constant coolant inlet temperature at a constant coolant-circulation

Transient analysis of simple automatic controls

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THE FUNDAMENTAL PRINCIPLES UNDERLYING THE PRESENT generation of nuclear power stations being built in the United Kingdom have been presented in previous articles in this series and elsewhere (*1*). It is intended here to examine the problem of the design of simple automatic systems for controlling the power of these reactors, and to study the dynamic performance of such controls. The kinetic behaviour of the nuclear power is examined in a simple manner, using a linearized transfer function, to demonstrate the effect of delayed neutron emission and its importance in the control of a nuclear reactor. The harmonic analysis of the combined system of nuclear reactor plus steam-raising plant has been described by Bowen in the second article of the series (Sep. and Oct. 1960). The development of the problem outlined below is suitable for use in analogue computer studies.

Components of reactivity

Since k_{eff} is of the order of unity when a reactor is at power, it is convenient to introduce a quantity

$$\Delta k = (k_{eff} - 1)/k_{eff} \qquad (1)$$

as discussed in the first article of the series (Aug. 1960).

Reactivity is normally controlled by lowering neutron-absorbing materials, such as boron steel rods, into special channels in the reactor core. The reactor is designed so that, with the absorbing rods not quite withdrawn from the core, $k_{eff} = 1$. A few control rods are allowed to project well in for automatic control of power.

Reactivity within a reactor is influenced by several different effects. The temperature of the fuel governs the absorption of neutrons by the infissile isotope of uranium, U^{238}. The hotter the fuel, the more neutrons are absorbed without causing fission. The fuel has a negative temperature coefficient of reactivity of the order of $-2{\cdot}5 \times 10^{-5}$ per degC. Initially the graphite moderator has a negative temperature coefficient of reactivity of the order of -2×10^{-5} per degC. This is associated with an increase in the moderator temperature and the average energy of the neutrons in the system. However, the longer the uranium fuel is in the reactor, the more the fissile isotope of plutonium, Pu^{239}, builds up from neutron absorption by the non-fissile isotope U^{238}. For constant core conditions other than moderator temperature, an increase in neutron energies increases the probability of free neutrons causing a fission in the Pu^{239}. After the fuel has been in the reactor for several months, the moderator temperature coefficient will become positive and finally rise to the order of 15×10^{-5} per degC. The effect of the temperature coefficients of reactivity of the fuel and moderator will be illustrated later (under *The uncontrolled reactor*, p. 99).

An important component of reactivity is that due to the production of fission products which either have a large capture cross-section for neutrons, or which decay radio-actively into isotopes with such a cross-section. The most important of these products is the xenon isotope, Xe^{135}. The radio-active decay chain producing this isotope is:

$$Te^{135} \xrightarrow{2\text{ min}} I^{135} \xrightarrow{6{\cdot}7\text{ h}} Xe^{135} \xrightarrow{9{\cdot}2\text{ h}} Cs^{135} \xrightarrow{2 \times 10^{6}\text{ a}} Ba^{135}$$

Te^{135} is produced directly from fission of U^{235}. This reaction has an important effect on the long-term stability of reactor power, as described by Vaughan in the preceding article. Since the time behaviour is long, it is not considered to play an appreciable part in the stability of the reactor over short periods. For the purposes of this

article, xenon poisoning within the reactor core is considered to be constant and balanced out by movement of the coarse control rods.

The controlled variable

The thermal power, P, where coolant enters at the bottom of the reactor core with temperature T_i and leaves the core with temperature T_o, is related to coolant mass flow by:

$$P = KW(T_o - T_i) \tag{2}$$

where K is a constant. The purpose of automatic control is to keep P constant by moving the fine control rods in the reactor core. P can be controlled directly by measuring the neutron flux in the core with a suitable ion chamber and actuating the control rods according to the error in the ion-chamber current. T_o can be controlled in accordance with thermocouple measurement, or a programmed variation of W and T_o can be used.

The behaviour of T_i depends on conditions in the heat exchangers. If steam pressures are held constant, the variation of T_i will be small compared with $(T_o - T_i)$. Heat exchangers can be designed to maintain a constant T_i by controlled by-passing of some of the feed-water around the economizer section to the evaporating section.

There are two main reasons for keeping T_o to a constant value. Firstly, to maintain a reasonable thermal efficiency on the steam side of the power station, the inlet temperature of the coolant gas to the steam-raising units should be kept as high as possible under all load conditions. Secondly, the thermal stressing of the fuel canning material must be minimized. The uranium fuel tends to distort during its useful life in the reactor owing to the building-up of gaseous fission products within the body of the fuel. The fuel-can, to maintain good thermal contact with the fuel, must distort in sympathy. If the canning material can be kept at a reasonably constant temperature, since the coolant outlet temperature depends on can temperature, the greater will be the life expectancy of the fuel elements.

Variables in control analysis

The number of neutrons present within the reactor per unit volume varies from place to place within the reactor core (see last month's article). The neutron density is a maximum at the centre but falls off towards the boundaries of the core. As a result the temperatures measured at any point will only be identical along symmetrical zones taking into account both geometrical symmetry and the direction of coolant flow. The equations representing transient behaviour will be partial-differential. In simplifying the equations, the variables are integrated throughout the volume of the reactor to yield a statistical average value that is representative of the behaviour of the reactor, as long as the shape of the neutron flux pattern only changes in magnitude but not in form (*2*).

Neutron kinetic equations

Proceeding from the equations given last month (p. 102), the neutron kinetics of a reactor can be represented by

NOMENCLATURE

k_{eff}	Neutron multiplication factor
Δk	$(k_{eff} - 1)/k_{eff}$
P	Reactor power, normalized to unity at full power
W	Coolant mass flow, normalized to unity at full flow
T_o	Reactor coolant outlet temperature, °C
T_i	Reactor coolant inlet temperature, °C
τ	Neutron mean lifetime, s
β	Total delayed neutron fraction
β_i	Fraction of delayed neutrons in the ith group
λ_i	Inverse time constant for the production of the neutrons in the ith group
P_i	Power of the ith delayed neutrons
δ	Prefix for a variation
T_u	Uranium fuel and canning temperature, °C
T_{uo}	Uranium fuel and canning temperature in steady state, °C
T_c	Average coolant temperature, °C
T_m	Average moderator temperature, °C
T_{mo}	Average moderator temperature in steady state, °C
α_u	Uranium temperature coefficient of reactivity
α_m	Moderator temperature coefficient of reactivity
ρ	Reactivity from the automatic control system
$h_1 \ldots h_5$	Coefficients in the reactor heat-transfer equations

$$\frac{dP}{dt} = (\Delta k - \beta)\frac{P}{\tau} + \sum_{i=1}^{6} \lambda_i P_i \tag{3}$$

$$\frac{dP_i}{dt} = \frac{\beta_i}{\tau} P + \lambda_i P_i \tag{4}$$

Here the normalized reactor power P is assumed to be proportional to the number of neutrons in the reactor core, β is the delayed neutron fraction and P_i is the power in a delayed neutron group i. Such a set of equations can be linearized for small variations to yield the Laplace transform*

$$\frac{\delta P}{\Delta k}(s) = \frac{P_o}{\tau} \cdot \frac{1}{s} \, \frac{1}{\left[1 + \frac{1}{\tau}\sum_{i=1}^{6} \frac{\beta_i}{(s + \lambda_i)}\right]} \tag{5}$$

where P_o is the steady-state power.

If Δk is a step function of magnitude A, the Laplace transform of the response is:

$$\delta P(s) = \frac{AP_o}{\tau} \cdot \frac{1}{s^2} \, \frac{1}{\left[1 + \frac{1}{\tau}\sum_{i=1}^{6} \frac{\beta_i}{(s + \lambda_i)}\right]} \tag{6}$$

The initial rate of rise of (6) can be obtained by multiplying (6) by s^2 and allowing s to tend to infinity, which gives:

$$\lim_{t \to \infty} \frac{d[\delta P(t)]}{dt} = \frac{AP_o}{\tau} \tag{7}$$

If $A = 0{\cdot}001$ and $\tau = 0{\cdot}001$ seconds, the initial rate of rise of δP is 100% of P_o per second. The final rate of rise of δP can be found by multiplying equation 6 by s^2 and allowing s to tend to zero.

$$\lim_{t \to \infty} \frac{d[\delta P(t)]}{dt} = \frac{AP_o}{\tau} \cdot \frac{1}{1 + \frac{1}{\tau}\sum_{i=1}^{6} \frac{\beta_i}{\lambda_i}} \tag{8}$$

* Cf. equation 9 in No. 2 of this series, Sep. 1960, p. 105.

$$\frac{1}{\tau}\sum_{i=1}^{6}\frac{\beta_i}{\lambda_i} \text{ is approximately 60 for uranium, so that}$$

$$\lim_{t \to \infty} \frac{d[\delta P(t)]}{dt} = \frac{AP_o}{61\,\tau}$$

Using the same values for A and τ, it is evident that the delayed neutrons reduce the final rate of power rise to $1/61th$ of the initial rate.

An approximate value for the total power rise, at the high initial rate, can be derived by assuming that the delayed neutron emitters produce neutrons at a constant rate for a short time after the disturbance. Since

$$\sum_{i=1}^{6} \beta_i = \beta, \text{ and that } \Delta k \text{ is constant for a step increase,}$$

$$\text{eq. 3 gives: } \delta P(s) = \frac{P_o}{\tau}\cdot \Delta k \frac{1}{\left(s + \frac{\beta - \Delta k}{\tau}\right)} \qquad (9)$$

$$\text{Therefore} \quad \lim_{t \to \infty} \delta P(t) = P_o \frac{\Delta k}{\beta - \Delta k} \qquad (10)$$

If $\beta = 0{\cdot}006$ and $\Delta k = 0{\cdot}001$, the initial power surge is $0{\cdot}143P_o$. Fig. 1 shows the approximations plotted together with a computed transient for a typical set of neutron kinetic equations following a $-0{\cdot}001$ step in reactivity.

Heat transfer equations

The form of these equations (*2*) for a simple reactor where only the heat transfer from fuel-plus-can to coolant, and coolant to moderator, is considered, are of the form:

$$\frac{dT_u}{dt} = aP - h_2W^{0\cdot8}(T_u - T_c) \qquad (11)$$

$$\frac{dT_c}{dt} = h_2W^{0\cdot8}(T_u - T_c) - h_3W^{0\cdot8}(T_c - T_m) - h_4\,W\,(T_c - T_{ci}) \qquad (12)$$

Fig. 1 (right) Response to a $-0{\cdot}001$ step in reactivity as shown by neutron kinetic equations. The approximation obtained from the linearized transfer function is dashed in

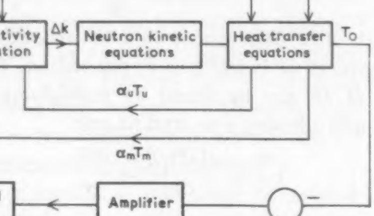
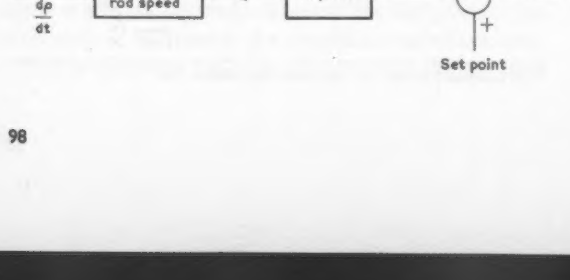


Fig. 2 (below) Block diagram of automatic control system for reactor



$$\frac{dT_m}{dt} = (1 - a)P + h_5W^{0\cdot8}(T_c - T_m) \qquad (13)$$

$$2T_c = T_o + T_i \qquad (14)$$

The term in P on the r.h.s. of equation 13 is a component of power in the moderator, partly due to the loss in kinetic energy of the neutrons on the thermalization and partly to the absorption of γ radiation. Equation 14 is an approximation suitable for a simple analysis. All the temperatures are average values as described earlier under *Variables in control analysis* (p. 97).

Only variations of reactor power P will be considered so that W, the normalized coolant circulation rate, will be unity. The coolant inlet temperature to the core, T_i, is also considered to be constant.

Reactivity equation

The reactivity equation is:

$$\Delta k = \alpha_u(T_u - T_{uo}) + \alpha_m(T_m - T_{mo}) + \rho \qquad (15)$$

This equation is written on the assumption that initially $\Delta k = 0$ and $\rho = 0$, and that the reactor is in equilibrium owing to the movement of the coarse control rods. ρ is the contribution of reactivity from the movement of the fine control rods under the automatic coolant-outlet-temperature control. It is undesirable that ρ should be able to undergo a large change if a fault should occur in the automatic control mechanism, so the motor which drives the control rod is limited in speed. The gain of the automatic control is given in terms of the reactivity change per second per degC change in coolant outlet temperature. The saturation, or limiting speed, is given in terms of the degC error in coolant outlet temperature to produce this speed.

Automatic control systems investigated

Two types of automatic control are considered. Firstly, a proportional rod-rate system where the gain of the controls is 5×10^{-7} per second per degC error in coolant outlet temperature, with a saturation speed corresponding to 20 degC. Secondly an on/off control where no rod movement occurs until the coolant outlet temperature is in error by 10 degC and correction is taken at a rate of 10^{-5}/s until the coolant outlet temperature is again within the ± 10 degC dead band. These figures are not the optimum values that would be used in practice, but are chosen for demonstration. These two control systems are shown in operation with two different reactor conditions. The first condition corresponds to the new, or unirradiated reactor, with a fuel temperature coefficient of $-2{\cdot}5 \times 10^{-5}$ and a moderator temperature coefficient of -2×10^{-5}. The second condition corresponds to a reactor after several months' operation, or irradiated, with a fuel temperature coefficient of $-2{\cdot}5 \times 10^{-5}$ and a moderator temperature coefficient of $+15 \times 10^{-5}$.

Fig 2 shows a block diagram of the system. T_o is assumed to be measured by a thermocouple in the outlet coolant gas stream with a negligible time delay. The

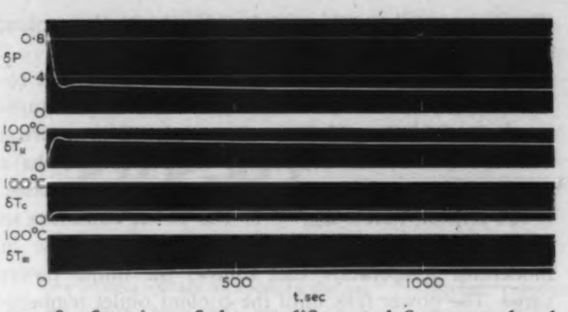


Fig. 3 (left) Transient response of an unirradiated power-reactor, with negative temperature coefficients of reactivity for fuel and moderator, to a +0·0018 step in reactivity with no controlling action

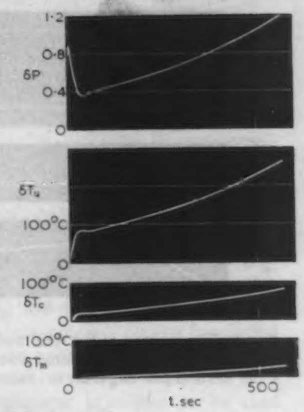


Fig. 4 (right) Transient response of an irradiated power-reactor, with negative temperature coefficient for fuel and positive coefficient for moderator, to a +0·0018 step in reactivity with no controlling action

transfer function of the amplifiers and fine-control-rod motor is considered to be a constant.

The following table lists the quantities that are needed for the interpretation of the analogue computer results.

Reactor and control system parameters

a Full-power steady-state conditions.

P	1	T_m	318°C
W	1	T_i	200°C
T_u	460°C	T_o	400°C
T_c	300°C	ρ	0

Variations from these steady-state values have a δ prefixed in the diagrams.

b Control system parameters

(*i*) Proportional control with saturation of control-rod speed.

Gain	-5×10^{-7}/s degC
Saturation speed	20-degC error in outlet coolant temperature.

(*ii*) On/Off control

Dead band	±10-degC error in outlet coolant temperature
Control-rod rate	$\mp 10^{-5}$/s outside the dead band.

c Coefficients of reactivity

Unirradiated reactor	$\alpha_u = +2{\cdot}5 \times 10^{-5}$/degC in T_u
	$\alpha_m = -2 \times 10^{-5}$/degC in T_m
Irradiated reactor	$\alpha_u = -2{\cdot}5 \times 10^{-5}$/degC in T_u
	$\alpha_m = +15 \times 10^{-5}$/degC in T_m

The uncontrolled reactor

The analogue-computer results are recorded as variations from the steady-state values listed in **a** of the table.

Fig. 3 shows the transient response of the unirradiated reactor, following a +0·0018 step-change in reactivity, computed on the analogue. The initial power surge is limited by the delayed neutrons and by the rise in fuel temperature in association with its negative temperature coefficient of reactivity. In 45 s the power drops to a minimum value and then rises by a small fraction owing to a slight drop in the peak value of the fuel temperature. The long time-constant of the moderator prevents much change in moderator temperature during the first hundred seconds. After this time the increase in heat production in the moderator and in coolant temperature produce a visible rise in temperature. A final steady state is reached after approximately 1250 s. At any point along this transient, once the power is varying slowly, the sum of the fuel and moderator temperature variations multiplied by their respective temperature coefficient of reactivity is always equal to the initial step of induced reactivity.

By equation 14, the rise in coolant outlet temperatures is twice the average coolant temperature in the core. Measured accurately on the analogue with a digital voltmeter, the coolant outlet temperature was 44 degC

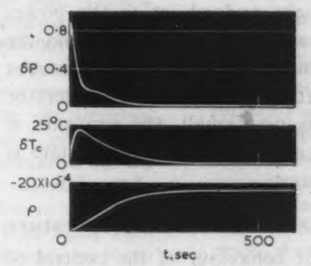


Fig. 5 (left) The reactor of Fig. 3 following a step in reactivity. Coolant outlet temperature automatically controlled. 5×10^{-7} of k per second per degC of error. Saturation rate for 20 degC error

above the normal steady-state temperature of 400°C. This, in conjunction with equation 2, shows that the final power should finally rise by 0·22 on the steady-state value, as recorded.

Fig. 4 shows the same step of reactivity on the irradiated reactor, without controlling action. The initial part of the transient is identical with that of Fig. 3 for the first twenty seconds. As soon as the moderator rises in temperature, the moderator temperature coefficient contributes positive reactivity more quickly than the increasing fuel temperature can offset with its own negative temperature coefficient. The result is that the reactor power diverges and is doubled in 480 s.

Automatic control of coolant outlet temperature with proportional rod-speed and saturation

Fig. 5 shows the transient behaviour of the unirradiated reactor following the +0·0018 step of reactivity. The control is as in **b**(*i*) of the table. The initial power peak is controlled by the delayed neutrons and the negative fuel temperature coefficient. The controller plays little or no part in this initial behaviour. In about 7 s the average fuel temperature has risen by 10 degC, corresponding to 20 degC change in coolant outlet temperature, by equation 14, and the controller-speed saturates. The control trims the reactor coolant temperature back to the original value in a well-behaved manner. The controller comes out of saturation after 120 s. The reactivity ρ from the controller is negative and offset by −0·00176 after 600 s. As the moderator cools to its initial value, so ρ increases to −0·0018, the initial step.

Fig. 6 shows the same automatic control system on the irradiated reactor. The system is now slightly underdamped. The gain of the controller is not sufficient to hold the set point once the moderator temperature has

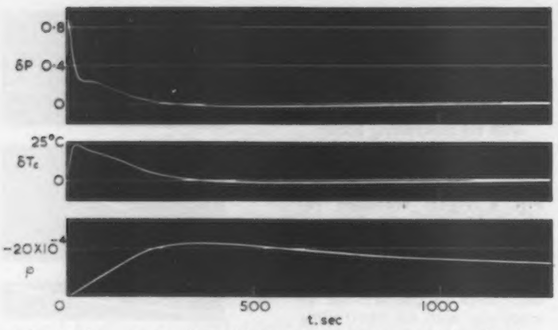


Fig. 6 The reactor of Fig. 4 following a step in reactivity. Coolant outlet temperature automatically controlled. 5×10^{-7} of k per second per degC error. Saturation rate for 20 degC error

started to move. The slight undershoot in the power after 300 s reduces the heat in the moderator, and the reactivity from the automatic control drops below the value of the initial step after 750 s. Since the moderator temperature fluctuation is now small, the rod gain is sufficient to hold the set point. A final steady state is reached after about one hour.

On/off control of reactor coolant outlet temperature

Fig. 7 shows the transient behaviour of the control of **b**(*ii*) of the table after a reactivity step of +0·0018. The initial shape of the power transient is again identical with that of Fig. 3. As soon as the average coolant temperature has risen by 5 degC and hence the outlet temperature by 10 degC the automatic control rods move into the reactor at a constant rate until the coolant temperature is once more within the controller dead band, and rod movement ceases. A small power rise at this time, owing to the liberation of delayed neutrons, is smoothed out by the thermal capacity of the fuel and can and is not evident in the average coolant temperature.

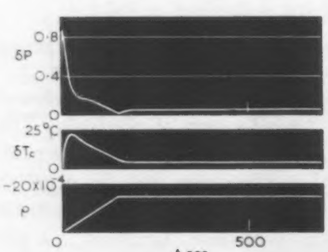
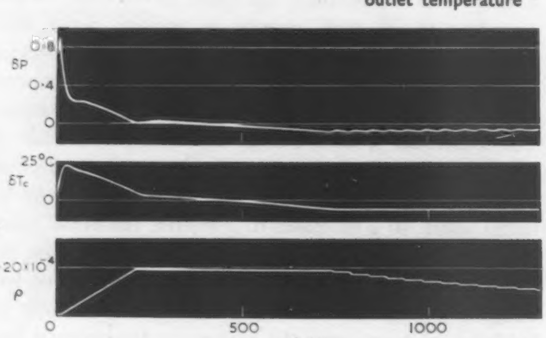


Fig. 7 (left) The reactor of Fig. 3 following a step in reactivity. On/off automatic control switching at ±10 degC error in coolant outlet temperature. 10^{-5} of k per second

Fig. 8 (below) The reactor of Fig. 6 following a step in reactivity. On/off automatic control switching at ±10 degC error in coolant outlet temperature



The system settles within the dead band with the coolant outlet temperature about 8 degC high.

Fig. 8 shows the same control on the irradiated reactor. The control rods move in, after the step disturbance of +0·0018, until the coolant outlet temperature is once more within the dead band. The control rods have moved so far that the reactor, when rod movement ceases, is sub-critical, that is $k_{eff} < 1$. The power continues to fall despite the reactivity contributed by the rise in moderator temperature that follows the initial power surge. The power falls until the coolant outlet temperature meets the other side of the dead band, and the automatic control rod inches out a small amount to give a rise in power. The moderator, cooling below the steady-state temperature during this time, introduces negative reactivity and the rods continue to inch out approximately every 40 s. This movement will continue at a decreasing frequency for about one hour until the system finds a steady state along the lower edge of the controller's dead band. This, however, is only a quasi-stable state, and a slight positive disturbance of reactivity will cause the system to drift to the top of the dead band, with a consequent inward inching of the control rods.

Application of analysis to real reactors

The transient behaviour of the proportional-plus-saturation control of coolant outlet temperature is favoured with graphite-moderated power reactors, since the reactor power, and thus the fuel can temperature, tends

NEXT MONTH

The seventh article in the series will be ' Control of blowers' by **G. H. Inglis** *of the U.K. Atomic Energy Authority.*

to undergo fewer sudden fluctuations than under the on/off control system. This is beneficial to the life of the fuel elements in the reactor. The analogue allows quick assessment of the value of phase advance of error networks and other control parameters with the control system. The performance of either of the automatic controls discussed can be greatly improved by such networks, and by the choice of higher gains in the proportional-plus-saturation system, and a smaller dead band in the on/off control.

The power distribution of a large reactor may not be spatially stable even though the outlet temperature is controlled, as was shown in last month's article. This means that power may be falling in one region and rising in another so that the coolant outlet temperature remains constant. Such instabilities are controlled by dividing the reactor core into regions (typically nine in number), measuring the coolant temperature error in each region, and using this error to actuate a local automatic control rod. This considerably complicates the overall problem.

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Pick-off by 'UNCONTROLLED'

SEVERAL OF MY FRIENDS in the industry have told me of their concern at the state of affairs described in *Control*'s leader last January. Since then Lord Hailsham has agreed to address the B.C.A.C. conference on automation in June, and this may be a first step towards more active Governmental interest. So far the prevalent official attitude has been that the best way to help industry is by specialized discussion rather than general conference. I know that many control engineers agree with me that a big push is needed on a much broader front. We must hope that the B.C.A.C. discussions will re-awaken national interest in a matter that is clearly of vital national importance.

SEEING THIS MONTH'S ARTICLE on the control of the big radio-telescope in Australia*, I am reminded of one of February's more interesting press conferences. This was a very well organized meeting at Mullard House, where Professors Ryle and Hoyle, of Cambridge, answered questions about the latest findings in cosmology. The conference was followed by Ryle's paper to the Royal Astronomical Society—and a great deal of desperate misunderstanding in the daily papers. Instrument engineers as well as astronomers are fascinated by the work of Ryle and his fellows, and it is a pity that the first published reports to reach many of us should have been so garbled.

PROFESSOR P. M. S. BLACKETT delivered the tenth Hinchley Memorial Lecture to the I.Chem.E. last month, and devoted himself once again to the serious problem of the 'under-developed' countries. He argued that propagating literacy is much less important than training labour for industry, and emphasized that only a relatively unsophisticated level of mechanization is wanted (in other words, no advanced automatic control). In this connexion—and apologizing for presuming as a physicist to put a technical point to chemical engineers, since chemical engineering is harder than physics—Blackett suggested that smaller plants should be made available for the u.-d. nations. (If everybody talked only of things he was expert in, added the professor, a deathly hush would fall upon the world.) He thought that fertilizers, pesticides and weed-killers were the three key products which chemical engineers could provide—they would be kept busy for a long time if they supplied the needed sulphate of ammonia alone. All this makes me wonder whether the right answer is to sell simple plant to u.-d. countries. Perhaps it would be better to offer them very cheap products from highly automated processes. I suppose this is another question for economists to put to their computers—if they can think up any valid program to express it in.

*See p. 84—EDITOR

ENGINEERS VISITING a recent computer conference in New York had an unusual opportunity to explore career opportunities in their field. A 'career center', sponsored co-operatively by employers, offered access to company literature, and the interested caller filled in a form with details of his education, experience and interests. These data (but not the visitor's name) were tabulated 'electronically' and immediately passed to all the participating companies. Firms which had an opening for the man sent an interview invitation to the reception desk. The engineer himself, having seen the company literature, could choose either to talk business or to turn down the invitation.

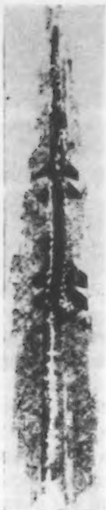
I hear that William A. Douglass, who is described as the 'creator of the career center concept', has said that recruiting at American conferences is one of the facts of life. According to Douglass, the typical job-changing procedure in the U.S. today is a round trip of the 'hospitality suites' at national or regional meetings: but there are obvious snags.

So hurrah once again for electronic computers—and another hot tip for the Ministry of Labour.

EMPHASIS ON SPEED being common to most considerations of computers, it is not surprising that their 'generations' succeed one another at a remarkable rate. Almost every new computer is hailed as 'the first of a new generation', suggesting that siblings, if they ever exist, are put to an early and painless death. As with humans, it is difficult in a computer population to define the limits of a generation, except inside a given family. *Design* (the journal of the Council of Industrial Design) in a recent issue felt that this rather ill-defined business of computer generations should be rationalized. Regretting 'the drab appearance of these British computers', *Design* concluded that 'the opportunity exists in a new generation of British computers . . . for ergonomic principles to be used as a firm foundation on which a more imaginative approach to appearance can be built up'. The exact principles to be used were not discussed, but a particular system was mentioned, with evident approval, in which 'the undersides of the three-desk consoles are red, with tops again in blue'. My wife tells me that apricot will be this summer's fashion, however, so computer people should take care.

PERHAPS I AM rather heartless in this respect, but I do derive a great deal of amusement from unwitting attempts to blind with the scientifically disguised obvious. There was the famous Dr Kinsey, for instance, who laboriously determined that girls brought up strictly and according to religious tenets are more likely to be chaste than those without such discipline behind them. Now there is Dr R. J. Smeed of the Road Research Laboratory, who, in a paper to the Manchester Statistical Society, recently set forth such conclusions as: *an extra vehicle on a congested road causes more congestion; parking near inter-*

sections and on narrow roads can cause long delays: and *traffic speed in the centres of large towns is decreasing:* blinding glimpses indeed! Yet I must not be too unkind, for this is at least an attempt to clarify an ever-worsening situation—something which the process engineer might well begin to undertake for the process-control man. Smeed gives a great deal of detail which may yet turn out to be useful. For example, we learn that, at peak, a person travelling one mile by suburban railway requires a square foot of ground-space (some of us have to squeeze into rather less), three square feet walking, five to eighty square feet car-borne, and four to ten square feet in a bus. Such are the statistics of the affluent society.



PART 2

Ideally, a different missile is wanted for every target. This is obviously not practical, and the control system has to provide for engagement at different ranges

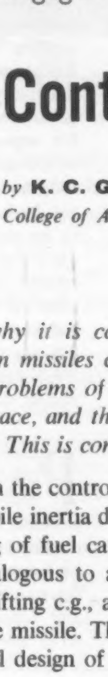
Controlling ballistic missiles

by **K. C. GARNER,** B.Sc.(Eng.), A.M.I.E.E., A.F.R.Ae.S.
College of Aeronautics, Cranfield

Last month we showed why it is convenient to use ballistic missiles rather than missiles controlled all the way. We introduced the problems of take-off and the dynamics of a rocket in space, and then opened a discussion of steering control. This is continued below.

A further complication in the control system is added by the existence of the mobile inertia due to fuel 'sloshing' (Fig. 3). This shifting of fuel cargo owing to the lateral accelerations is analogous to a lightly damped variable mass, having a shifting c.g., and suspended by a low-rate spring within the missile. This effect depends a great deal on the internal design of the tanks, and if

Fig. 3 Effect of fuel sloshing



the control loop cannot be designed to accommodate this additional destabilizing force, then baffles to reduce the sloshing must be fitted within the tank interior. The penalty is, of course, extra weight. It is beyond our scope here to consider the control relationships explicitly.

Consideration of the trajectory shows that, providing the missile's burn-out velocity and angle of flight are right, the altitude at which burn-out occurs does not introduce a particularly serious error. Thus there is a possibility that the actual position of the missile for certain trajectories is relatively unimportant, and that it may be possible simply to concentrate on getting the all-burnt velocity and the all-burnt flight-path angle correct to achieve a satisfactory trajectory.

The flight plan of a ballistic missile is such that there is a take-off phase which is vertical, or nearly so. This lasts long enough for the vehicle to clear the reaches of the atmosphere, after which a turn-over program commences. This phase can be achieved in a variety of ways, depending on the particular instrumentation of the missile and the designer's preference. The phase lasts until the desired azimuth and elevation angles of flight occur, the former being by far the most important for a minimal-velocity trajectory. From then on a straight-line trajectory is pursued until the vehicle accelerates up to the desired cut-off velocity. The last two phases may be allowed to occur simultaneously, but since there is no control over the thrust it is usual to arrange that the desired vector occurs before burn-out. Note that this procedure is entirely similar to a satellite launching (*4, 7, 8*), with only one significant difference. In the case of the ballistic missile any angular velocity of the vehicle at cut-off, although it would cause 'tumbling' of the war-head during the free-flight trajectory, would not in general be inadmissible, although undesirable, on re-entry. For a satellite, however, such a fortuitous motion is not generally acceptable.

There are three obvious choices for the control of the trajectory. If the missile's position is measured continuously, either by an internal inertial navigator or by ground Doppler radar, or both, then it can be steered by its autopilot along a desired path until the predetermined velocity is achieved. If the missile's flight direction or velocity is measured by similar means, then the desired flight-path angle can be set up and main-

CORRIGENDA: We very much regret certain printers' errors in Part 1 last month. Eq. (2) should have appeared as $m\ddot{y} = T \sin(\theta + \zeta)$, eq. (3) as $C\ddot{\theta} = -Tl \sin \zeta$, eq. (9) as $\ddot{\theta} = -\zeta/T_2^2$ and eq. (12) as $T_2^2 = C/ml\dot{U}$. The caption to Fig. 2 should have had $\ddot{y}_z$ in the sixth line, not y_z as it appeared in some copies.—EDITOR.

tained until the correct velocity is reached. If the missile's accelerations are measured then the flight direction can again be set up with a suitable computer, until a desired cut-off velocity condition is reached. Two points are worth noting. 1 If the missile gains the desired all-burnt velocity and still has any appreciable quantity of fuel left, then of course the design is not optimal, since this excess fuel has been an unnecessary lifted weight, and the penalty for it is either reduced range or a greater take-off weight. One of the major problems, which is of great interest to the control engineer, is associated with the correct use of 'bi-propellants'. The important factors affecting the weight of unusable fuel at true burn-out are mainly due to unsatisfactory control of mixture ratio during flight, causing one of the components to exhaust before the other, and presumably not providing the best thrust capability of the motor. Also, consideration must be given to entrained fuel left in the auxiliary-fueling-system pipework and pumps (*4*, *9*). Thus some attempt is made to minimize this unwanted fuel weight. 2 The optimum velocity, determined as shown in the appendix, gives the longest range for a given missile, and incidentally minimizes the effect of elevation error. Therefore the maximum operational range specified for the missile and the conditions for the desired velocity must be very carefully matched. A given missile is most efficient against targets lying on a circle of radius equal to its maximum range, centred at the launching point. Ideally, a different missile is required for every target to achieve optimum design in each case. Overall, of course, so many different missiles would not be the optimum solution, for obvious reasons, so that the control system must facilitate engagement of shorter-than-maximum-range targets. This means the possibility of either earlier motor cut-off, or a higher tangential elevation, or both. Practically, burn-out is achieved by *allowing* the fuel or its oxidant to become exhausted, or by cutting off the supply by means of a computer-actuated valve. The computer may be fed with data from the dynamic instrumentation, or may simply be a time-programmed device. This control may take place within the missile or initiated remotely from the ground from flight data obtained by Doppler measurements. Errors in properly achieving this cut-off, say of about one second, can produce range errors in the order of eighty miles in 1500 miles, if the final acceleration is $10g$ (*9*).

Instrumentation

Whatever combinations of the measurable variables are used to steer and stabilize a particular missile during its control phase, the internal instrumentation used is inevitably an arrangement of accelerometers, free and rate gyroscopes, and other sophistications of these. Certain special considerations when they are used for ballistic-missile guidance are worth mentioning. Accelerometers measuring rectilinear motion in association with an inertial navigator require to have a zero error better than $2{\cdot}5 \times 10^{-3}g$ to give a missile-velocity error of less than 20 ft/s after about three minutes' flight time. This would give a range error of something like a mile against a 4000-mile-distant target. Gyroscopes for use with such inertial references also have to have extremely low wander rates under external accelerations, and for similar range accuracy the figure is of the order of $0{\cdot}5°$/h per g. These figures may be met at the cost of some extremely arduous and precise engineering development. Because of the low natural periods in these large missiles, however, no very difficult requirements exist for frequency response. The Schuler, or 84-minute, pendulum is not usually used, since the control phase only lasts for a small fraction of this time, and the ordinary inertial platform and external radar methods are generally adequate.

The outstanding need

While this article has not pretended to give a precise or detailed description of ballistic-missile control and guidance, it has set out to show the nature of the immensely difficult control problem facing the missile designers. One thing more than any other stands out. That is the tremendous importance of integrated design, when weight and reliability are at a premium. Both the Americans and the Russians have claimed miss-distances within 2·5 miles at ranges of 3000 and 5000 miles respectively, so apparently it can be done.

APPENDIX

Elementary theory of ballistic missile trajectories

1. The Ellipse

All ballistic missile trajectories and satellite orbits, with suitable assumptions, are conic sections, and by far the most important is the ellipse.

Fig. 4 shows the ellipse where F_1 and F_2 are the foci.

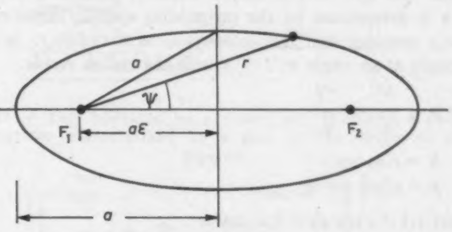


Fig. 4 The ellipse

The equation for this particular conic section is

$$r = \frac{a(1 - \varepsilon^2)}{(1 - \varepsilon \cos \psi)} \qquad (1)$$

when $\psi = \frac{\pi}{2}, \frac{2\pi}{2}$ $\quad p = a(1 - \varepsilon^2)$ = semi-latus rectum

when $\psi = 0$ $\quad r_a = a(1 - \varepsilon)$ = radius at apogee

when $\psi = \pi$ $\quad r_p = a(1 - \varepsilon) = ap$ = radius at perigee

a = semi-major axis

$b = \sqrt{[a^2(1 - \varepsilon^2)]}$ = semi-minor axis

2. The central force orbit

Assume a particle, p, acted upon by a force directed through a single point, O, in space, then the equation of its motion can be resolved into two components, along the force direction, and normal to it.

Hence, referring in Fig. 5

$$r\ddot{\psi}+2\dot{r}\dot{\psi}=0$$

$$\ddot{r}-r\dot{\psi}^2=-\frac{\mu}{r^2}$$

where μ = constant and the inverse square law is assumed.

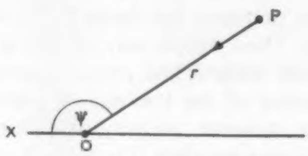


Fig. 5 Motion of a particle

By denoting $\quad r=\dfrac{1}{U}\quad$ and $\quad h=r^2\dot{\psi}=$ constant

it can be derived that $\quad \dfrac{d^2U}{d\psi^2}+U=\dfrac{\mu}{h^2}$

and by choosing suitable axes the solution is

$$U=\frac{\mu}{h^2}-A\cos\psi=\frac{1}{r}$$

Now let $\quad \dfrac{\mu}{h^2}=\dfrac{1}{p}\quad$ and $\quad \varepsilon=Ap$

then
$$r=\frac{p}{1-\varepsilon\cos\psi} \tag{2}$$

where if $1>\varepsilon>0$, the curve is an ellipse
and $\quad p=a(1-\varepsilon^2)$
Equation 2 may also be written in the form

$$r=\frac{h^2/\mu}{1-\left(1+\dfrac{2h^2E}{\mu^2}\right)^{\frac{1}{2}}\cos\psi} \tag{3}$$

where $\quad E$ = total energy $=\frac{1}{2}(v^2-v_E^2)$ (4)
$\quad v$ = particle velocity
$\quad v_E$ = the escape velocity:
so that the size of the ellipse depends on the total energy which is determined by the propulsion specific impulse.

Next consider that the velocity v_t at a radius r_t is instantaneously at an angle $\pi/2-\alpha$ with the radius vector.

Since $p=\dfrac{h^2}{\mu}=\dfrac{r^4\dot{\psi}^2}{\mu}$

then $\quad h=r_tv_t\cos\alpha$
or $\quad p=r_t^2v_t^2\cos^2\alpha$

So that $\quad r(1-\varepsilon\cos\psi)=Kr_t\cos^2\alpha \qquad (5)$

where $\quad K=\dfrac{r_tv_t^2}{\mu}$

Now let $\quad \psi=\psi_t\quad$ when $\quad r=r_t$
Thus $\quad 1-\varepsilon\cos\psi_t=K\cos^2\alpha \qquad (6)$
Differentiating equation 5

$$\dot{r}(1-\varepsilon\cos\psi)+r\varepsilon\sin\psi.\dot{\psi}=0$$

Since initially $\quad \dot{r}=v_t\sin\alpha\quad$ and $\quad r\dot{\psi}=v_t\cos\alpha$
then
$$(1-\varepsilon\cos\psi_t)\sin\alpha+\varepsilon\sin\psi_t\cos\alpha=0 \tag{7}$$
Hence by eliminating ψ from equations 6 and 7
$$\varepsilon^2=K(K-2)\cos^2\alpha+1 \tag{8}$$
For $0<K<2$ and $0<\varepsilon<1$, the trajectory is elliptical. For $K>2$ the particle 'escapes', and the initial velocity for escape is given when $K=2$ as
$$v_E=\sqrt{(2\mu/r_0)} \tag{9}$$
For any general launching velocity, v_L, and since $g=\mu/R^2$
$$r(1-\varepsilon\cos\psi)=KR\cos^2\alpha \tag{10}$$

where
$$K=\frac{Rv_L^2}{\mu}=\frac{v_L^2}{Rg} \tag{11}$$
$\quad R$ = earth's radius
$\quad g$ = gravitational force at earth's surface

Range calculations

The convenient way to measure ballistic range is to consider the angle between launching point and target. The elliptical trajectory must of course intersect the earth's surface at these two points, as shown in Fig. 6.

Therefore for $v_L<v_E$ assume a target at distance 2ϕ. Then for a given v_L, α must be adjusted to generate the required intersecting ellipse.

Hence
$$\cos\phi=\frac{1-K\cos^2\alpha}{\varepsilon} \tag{12}$$
and from equation 8
$$\cos\phi=\frac{1-K\cos^2\alpha}{\sqrt{K(K-2)\cos^2\alpha+1}} \tag{13}$$
or
$$\cot\phi=\frac{1-K\cos^2\alpha}{K\cos\alpha\sin\alpha}=\frac{\sigma-\cos2\alpha}{\sin2\alpha} \tag{14}$$
where
$$\sigma=\frac{2-K}{K}=\frac{2Rg}{v_L^2}-1 \tag{15}$$
Given a particular ϕ, i.e. target range $(0<\phi<\pi/2)$
$$\frac{d\sigma}{d\alpha}=2(\cot\phi\cos2\alpha-\sin2\alpha) \tag{16}$$

As α varies from 0 to $\pi/2$, there is a maximum for σ at $\alpha_0=\pi/4-\phi/2$, which, from equation 15, means that there is a minimum value of v_L.

Thus this value of α gives $\sigma=\dfrac{1}{\sin\phi}$ so that

$$v_{L0}=\left(\frac{2Rg\sin\phi}{1+\sin\phi}\right)^{\frac{1}{2}}=v_E\left(\frac{\sin\phi}{1+\sin\phi}\right)^{\frac{1}{2}} \tag{17}$$

where α_0 and v_{L0} are the optimum trajectory elevation and cut-off velocity values respectively.

All the above analysis assumed a spherical non-rotating homogeneous earth with no atmosphere.

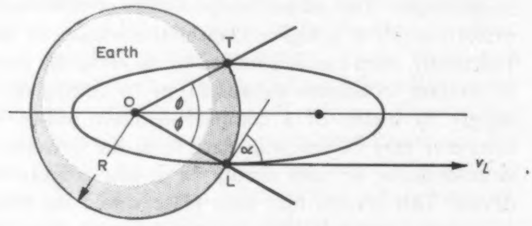


Fig. 6 Trajectory and earth

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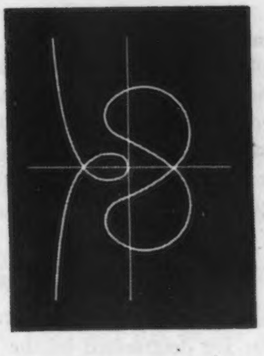
Acknowledgements

I should like to express my appreciation to Professor G. A. Whitfield and Mr J. A. Milner, both of The College of Aeronautics, for the free use of lecture material, which was invaluable in the presentation of this article.

End



NUMBER FOUR OF THE SERIES **PART B**

'Closing the loop' can be considered as a redistribution of the poles and zeros of a system in the complex plane.

Pole-zero approach to system analysis

by **P. F. BLACKMAN**

Imperial College of Science and Technology

In Part A last month we surveyed methods of analysis for closed-loop systems and gave some examples of the root locus approach. Further illustrations follow below.

a *Single integration*

A unit with a single integration transfer is represented ideally by a ram supplied with pressure oil through a valve as in Fig. 11. The valve displacement x controls the oil flow into the cylinder so that the ram velocity is directly related to the valve displacement by

$$dy/dt = K_r x$$

or

$$y = K_r \int x \, . \, dt$$

where K_r is a constant of proportionality. A complex frequency substitution into the differential relation leads to the transfer

$$Y(p)/X(p) = K_r/p$$

characterizing the unit by a single pole at the origin corresponding with the integrating action, and giving a 180° line along the negative real axis.

The transfer between supply voltage and shaft angle for a shunt electric motor with constant field current as in Fig. 12, is of the form*

$$\theta_o(p)/E_s(p) = K_s/p(1 + p\tau_m)$$

where K_s, τ_m, depend on the motor parameters. The unit contains an integration action between voltage and shaft angle analogous to the valve : ram relation for the hydraulic unit, but there is an additional time constant due to a combination of mechanical and electrical effects, and this time constant is not zero even if the motor is unloaded. The transfer is characterized by a

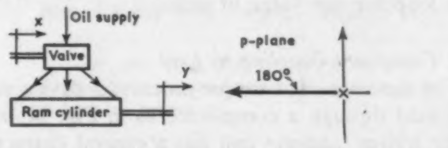


Fig. 11 A ram operated by pressure oil represents a single integration, characterized by a pole at the origin in the p-plane

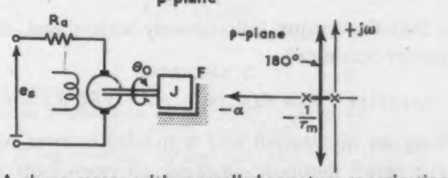


Fig. 12 A shunt motor with controlled armature energization represents a single integration and an additional time-constant

pole at the origin and an additional pole on the negative real axis. If the unit is incorporated in a loop lightly damped natural modes may be obtained for increasing values of gain.

b *Double integration*

A method commonly used to control small motors is to supply the armature with a (nominally) constant current and vary the field energization from an amplifier

* Appendix A

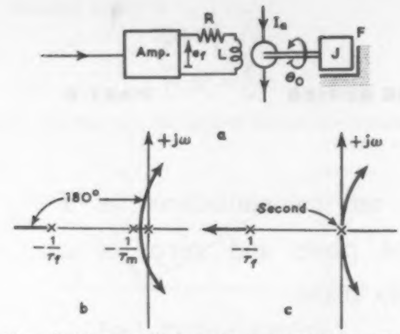


Fig. 13 a Field-controlled constant-armature-current motor. **b** Pole pattern with finite viscous damping. **c** Pole pattern with zero damping

as in Fig. 13a. This arrangement contains an integration and two independent time-constants, one due to the motor field and the other to viscous damping and inertia, giving a transfer of the form*

$$\theta_o(p)/E_f(p) = K_t/p(1 + p\tau_m)(1 + p\tau_f)$$

where $\tau_m = J/F$ $\tau_f = L_f/R_f$.

A pair of 180° lines cross the imaginary axis, so the unit could be incorporated in a loop, but with only limited gain before maintained oscillations occurred. If, to consider an ideal case, the viscous damping is zero, the transfer of the unit takes the form*

$$\theta_o(p)/E_f(p) = K_t/p^2(1 + p\tau_f)$$

giving a second-order pole at the origin corresponding to a double integration, since an applied voltage would now cause continuous acceleration. The 180° lines in Fig. 13c, show that such a unit would be unstable in a loop for any value of gain.

c *Compliant coupling to load*

For the case of a torque-generating device coupled to a load through a compliance as in Fig. 14, where q is the torque, and the unit has a general characteristic

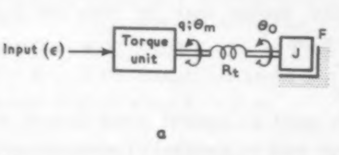
$$Q(p) = K_t E - K_m p\theta_m$$

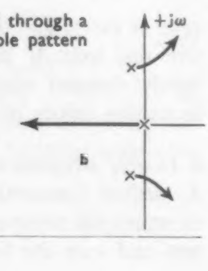
so that the torque falls linearly with speed, the overall transfer becomes†

$$\theta_0(p)/E(p) = K_t/p[p^2 JK_m/R_t + p(J + FK_m/R_t) + F + K_m]$$

giving an integration and a quadratic term which may have small damping showing an open-loop resonance and 180° lines of the general form of Fig. 14b, tending

Fig. 14 a Torque unit connected to load through a compliant coupling. **b** Corresponding pole pattern





* Appendix B † Appendix A

to instability when included in a loop. Hydraulic units can have this form of transfer if oil compressibility is taken into account.

More general conditions

In the examples considered so far it has been tacitly assumed that the forward path of the system alone contained a frequency-dependent function with poles only. The more general case is where both forward and backward paths are ratios of polynomials, as in Fig. 15a, yielding the closed-loop transfer

$$T(p) = \frac{K_t N_f/D_f}{1 + K_t N_b N_f/D_b D_f} = \frac{K_t D_b N_f}{D_f D_b + K_t N_f N_b}$$

where K_t represents gain independent of frequency. The closed-loop poles are determined by the 180°-line system of the complete path containing forward and backward portions, i.e., the condition

$$K_t N_b N_f/D_b D_f = -1$$

In addition, the closed-loop transfer contains the original zeros of the forward path N_f, and the backward-path poles D_b also appear as zeros.

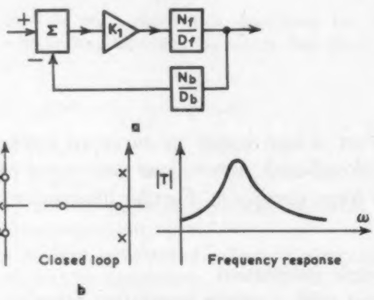


Fig. 15 a General closed-loop system. **b** System with twin tee in feedback path

For the rather special case of a frequency-dependent portion in the backward path alone, the closed-loop transfer becomes

$$T(p) = K_t D_b/(D_b + K_t N_b)$$

and if the gain $K_t \gg 1$, the closed-loop poles are forced very close to the open-loop zeros since the poles are determined by

$$|N_b/D_b| = -1/K_t$$

In this manner the pattern of a backward path can be very nearly inverted in the plane. For instance, a twin-tee network in the backward path gives a form of selective amplifier, since the closed-loop poles occur close to the imaginary axis, as in Fig. 15b.

Redistribution of poles and zeros

The actual process of closing a loop can be considered as achieving a redistribution of position of the system's poles and zeros in the complex plane, the essential feature being that it is not possible to create or destroy poles or zeros as far as the total number

for the complete loop is concerned. With a frequency-dependent term in both forward and backward paths the complete open-loop transfer becomes

$$\frac{N_b N_f}{D_b D_f} = \frac{p^m + a_i p^{(m-1)} + \ldots}{p^n + b_i p^{(n-1)} + \ldots}$$

which contains a number of poles n equal to the combined order of the denominators. Also there will be a number of zeros m equal to the combined order of the numerators. There will be a zero of order $(n-m)$ at infinity, and the complete path will contain

n poles (finite)
m zeros (finite) $\}$ total n zeros
$(n-m)$ zeros (infinite)

giving equal numbers of poles and zeros. When the loop is closed there will still be the same number of poles n, which will be repositioned in the plane, though

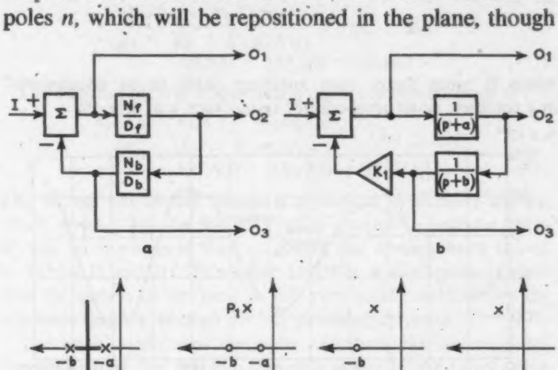


Fig. 16 a Possible outputs from general system. b A particular case. c Transfer patterns for case b

the number of finite zeros may change. For the general closed-loop case, three transfers may be considered, as in Fig. 16a,

$$\frac{O_1}{I} = \frac{D_f D_b}{D_f D_b + N_f N_b}, \quad \frac{O_2}{I} = \frac{N_f D_b}{D_f D_b + N_f N_b}, \quad \frac{O_3}{I} = \frac{N_f N_b}{D_f D_b + N_f N_b}$$

In each case the poles of the transfers are the same, but the number of finite zeros will depend on the actual output point chosen.

As an example, the case of Fig. 16b gives the open-loop transfer

$$\frac{O_3}{I}(open\text{-}loop) = \frac{K_1}{(p+a)(p+b)} \quad \begin{cases} \text{2 finite poles} \\ \text{2 infinite zeros} \end{cases}$$

and if the closed-loop poles are p_1, $\bar{p}_1$, the three transfers are

$$\frac{O_1}{I} = \frac{(p+a)(p+b)}{(p-p_1)(p-\bar{p}_1)} \quad \begin{cases} \text{2 finite poles} \\ \text{2 finite zeros} \end{cases}$$

$$\frac{O_2}{I} = \frac{(p+b)}{(p-p_1)(p-\bar{p}_1)} \quad \begin{cases} \text{2 finite poles} \\ \text{1 infinite zero} \\ \text{1 finite zero} \end{cases}$$

$$\frac{O_3}{I} = \frac{1}{(p-p_1)(p-\bar{p}_1)} \quad \begin{cases} \text{2 finite poles} \\ \text{2 infinite zeros} \end{cases}$$

showing the repositioning of the poles and the movement of infinite zeros on to the finite plane.

APPENDIX A

Shunt motor with constant field energization

The torque generated by the motor is proportional to the armature current

$$q = K_t i_a$$

where q = torque, i_a = armature current, K_t = torque/amp. The armature current is determined by the difference between supply voltage and armature back-e.m.f.

$$R_a i_a = e_s - K_b \frac{d\theta_o}{dt}$$

where R_a = armature resistance, K_b = generated volts per (rad/s) θ_o = shaft angle, e_s = supply volts.

The torque equation for the load gives

$$q = J\frac{d^2\theta_0}{dt^2} + F\frac{d\theta_0}{dt}$$

where J = moment of inertia, F = viscous friction constant.

Complex frequency substitutions may be made into the above equations to give

$$Q = K_t I_a,\ I_a = (E_s - K_b p\theta_0(p))/R_a,\ Q = (Jp^2 + Fp)\theta_0(p)$$

and I_a, Q may be eliminated to yield

$$\frac{\theta_0}{E_s}(p) = \frac{K_s}{p(1 + p\tau_m)}$$

where

$$K_s = K_t/(F + K_b K_t),\ \tau_m = JR_a/(F + K_b K_t)$$

If $F \to 0$ the motor time constant is still finite with the value

$$\tau_m = JR_a/K_b K_t$$

APPENDIX B

Field-controlled motor with constant armature current

If complex frequency forms are assumed, the field current is related to the field voltage by

$$E_f = (pL_f + R_f)I_f$$

and the torque equation gives

$$Q = (Jp^2 + Fp)\theta_0(p)$$

and

$$Q = K'_t I_f$$

where K'_t = torque/field amp.

If Q, I_f are eliminated the resulting transfer becomes

$$\frac{\theta_0}{E_f}(p) = \frac{K'_t}{p(pL_f + R_f)(Jp + F)} = \frac{K_1}{p(p\tau_m + 1)(p\tau_f + 1)}$$

where

$$K_1 = K'_t/FR_f,\ \tau_m = J/F,\ \tau_f = L_f/R_f$$

giving a system containing two independent time-constants.

If $F \to 0$ the transfer becomes

$$\frac{\theta_0}{E_f}(p) = \frac{K'_t}{p^2 J(pL_f + R_f)} = \frac{K_2}{p^2(p\tau_f + 1)}$$

where

$$K_2 = K'_t/JR_f$$

giving a double integration with a single time constant.

APPENDIX C

Compliant coupling to load

The torque transmitted to the load is given by

$$Q = [\theta_m(p) - \theta_0(p)]R_t$$

where R_t is the torsional spring rate, also

$$Q = (Jp^2 + Fp)\theta_0(p)$$

Since from the torque unit characteristic

$$Q = K_t E - K_m p\theta_m(p)$$

the pair of equations are obtained

$$K_t E - K_m p\theta_m(p) = [\theta_m(p) - \theta_0(p)]R_t,\ D - K_m p\theta_m(p) = (Jp^2 + Cp)\theta_0(p)$$

and θ_m may be eliminated to give

$$\frac{\theta_0}{E}(p) = K_t/p[p^2 JK_m/R_t + p(J + K_m F/R_t) + F + K_m]$$

General references on the root-locus method

1. Aseltine, J. A.: *Transform Method in Linear System Analysis* (McGraw-Hill Book Co., 1958).
2. Bower, J. L., and Schultheiss, P. M.: *Introduction to the Design of Servomechanisms* (John Wiley and Sons Inc., 1958).
3. Evans, W. R.: *Control System Dynamics* (McGraw-Hill Book Co., 1954).
4. Truxal, J. G.: *Automatic Feedback Control System Synthesis* (McGraw-Hill Book Co., 1955).

PART 5 The degree of stability depends on how the pumps are governed, and all systems become less stable when the load goes up

Boiler feed discharge systems under changing load

by **A. J. MORTON,** M.Sc., A.M.I.Mech.E.
Central Electricity Generating Board

At the close of last month's instalment we were giving a specimen calculation for a system with a Venturi-governed pump. This is continued below.

Response to regulator movements

Using the constants in Table I applicable to this type of governing, the following equations are obtained:

For 100% load:

$$[1+0{\cdot}455D+0{\cdot}00866D^2]\,Q \;=0{\cdot}00209\,T_0+6{\cdot}30[1+0{\cdot}0404D]y$$

or

$$[(1+0{\cdot}435D)(1+0{\cdot}020D)]\,Q \;=0{\cdot}00209\,T_0+6{\cdot}30[1+0{\cdot}040D]y \tag{68}$$

For 50% load:

$$[1+0{\cdot}1893D+0{\cdot}00414D^2]\,Q \;=0{\cdot}000998\,T_0+4{\cdot}90[1+0{\cdot}0402D]y$$

or

$$[(1+0{\cdot}165D)(1+0{\cdot}025D)]\,Q \;=0{\cdot}000998\,T_0+4{\cdot}90[1+0{\cdot}0402D]y \tag{69}$$

For 10% load:

$$[1+0{\cdot}0607D+0{\cdot}000732D^2]\,Q=0{\cdot}000177\,T_0+5{\cdot}64[1+0{\cdot}0406D]y$$

or

$$[(1+0{\cdot}044D)(1+0{\cdot}017D)]\,Q \;=0{\cdot}000177\,T_0+5{\cdot}64[1+0{\cdot}0406D]y \tag{70}$$

Comparison with equation 29 gives the values for T_1, T_2, T_3 and C_1 shown in Table III. As in the previous example, minor arithmetical discrepancies will be found, but the effort of eliminating these would not be justified by the inherent crudeness of the basic assumptions.

The time response of the flow rate Q to a sudden increase of $1/C_1$ in the regulating valve lift y is plotted in Fig. 3 for different nominal loads. It will be seen that at the full load condition the curve is almost identical with a simple exponential response of time constant T_1. This is less true for the 50% load condition, and not at all true for 10% load, but since the full-load condition is the least stable the others are of academic interest only.

Fig. 4 shows the amplitude and phase of the flow rate oscillations resulting from a sinusoidal variation in regulating valve lift y of amplitude $1/C_1$ and frequency $\omega/2\pi$. The full load curve is not very different from that given by a system with a simple exponential delay of time constant T_1, except at very high frequencies which are probably of little practical importance and for which the equations cease to be valid.

As an example, a phase lag of 20° would occur at full load if the regulating valve were to oscillate at the frequency corresponding approximately to $\omega T_1 = 0{\cdot}4$: or $\omega = 0{\cdot}9\ \mathrm{s}^{-1}$ taking $T_1 = 0{\cdot}44$ s, the corresponding frequency being $0{\cdot}9/2\pi = 0{\cdot}14$ c/s, which is much faster than anything likely to be encountered in a complete water-level-control system (see, e.g., Fig. 9).

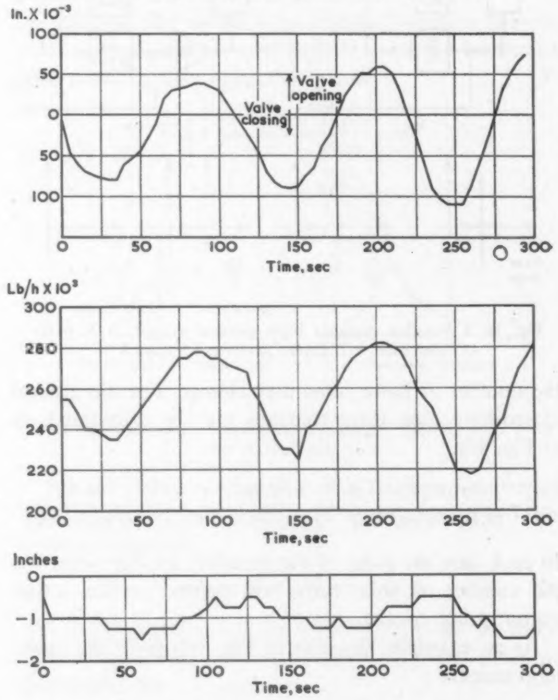


Fig. 9 Oscillations in feed discharge system of large marine power plant.

Conclusions

1. From the results above, *this particular system* may be expected to behave very much as if it contained a single delay T_1.
2. The constant T_1 (see equations 68–70) is always roughly equal to the coefficient of DQ, and as the basic theory is not sound enough to justify more than rough calculations, there is no point in calculating any other terms.
3. This particular Venturi-governed system is quite stable by itself *when operated in its designed condition,* and the phase lag in the response of flow rate to regulating valve movement is very small for the frequencies likely to be of practical significance. The system is therefore unlikely

to be a major cause of instability, whatever may be the characteristics of the boiler and feed regulator control system with which it is associated.

It is not yet known whether conclusions 1 and 2 are true for most systems or whether this is an isolated instance. If they are generally true, the theory could be applied in rough design checks with comparative ease.

Conclusion 3 does not hold if the system is not operated in its designed condition, a matter discussed further below.

Onset of instability

Condition for stability of pump and discharge system

For the pump, turbine, governor and discharge system to form a stable combination, the denominator in the coefficients of D and D^2 in equation 20 or 23 must be positive, as explained already. For the pressure-governed system, equation 20 applies, and, using numerical values from Table I, the denominator is

$$\frac{K_P(K_R - K_G K_Q K_W)}{(K_D + K_T + K_G K_P K_W)} + (K_Q + K_S)$$
$$= -69{,}500 + 153{,}300 = 83{,}800 \qquad (71)$$

The addition of Venturi governing alters the denominator to

$$\frac{K_P(K_R - K_G K_Y - K_G K_Q K_W)}{(K_D + K_T + K_G K_P K_W)} + (K_Q + K_S)$$
$$= -127{,}600 + 153{,}300 = 25{,}700 \qquad (72)$$

This brings out clearly the great reduction in stability margin which arises from the use of Venturi governing, and the effect of this on the system time constants has already been shown in Tables II and III. This table, and Fig. 4 also, make it clear that the system *as designed* is still very stable and follows the regulator quickly enough for all practical purposes.

The actual *stability* of the pump and discharge system alone, as opposed to that of the complete water-level-control loop, depends only on the above denominator, and is therefore independent of the rotational inertia of the pump and turbine and of the translational inertia of the water column in the discharge system. Variations in these two items do not affect stability, although they do affect the time constants and hence the speed of response.

Stability of the complete control loop is however a different matter, as already explained. It is dependent upon the time responses of all its components, and is therefore affected by all the constants of equations 15, 17, 20 or 23 except T_0, which is merely a result of the adoption of an arbitrary zero for the fundamental variables and has no significance whatever for the present purpose.

Effect of departures from design

Excessive Venturi action

It is obvious that if the Venturi term K is large enough and other constants remain unchanged, the denominator (72) will become zero or negative, and instability will result. This will occur if K is increased from 0·1932 to 0·2795 s/ft², giving an equilibrium discharge pressure characteristic rising from 555 lb/in² gauge at no load to 650 lb/in² gauge at full load.

As the full-load pressure-drop in the discharge system, excluding regulator, is supposed to be only 50 lb/in² gauge in this example, a rise in discharge pressure of 95 lb/in² gauge from no load to full load would not be specified in the pure light of reason. Such a governor might however be installed if the pump designer had been given an overestimated figure for the system pressure loss, and other possible reasons will occur to anyone familiar with steam-plant design and operation.

Low system resistance

The constant K_s at any given load is directly proportional to the total system resistance including that of the feed regulator, and it is immaterial in what part of the system the resistance arises. With a given feed-pump discharge characteristic, the flow is controlled by adjusting the feed regulating valve, thus varying the total system resistance, and if the pipework resistance is unexpectedly low this will be counteracted by reduced opening of the regulating valve at any given flow. The same thing will occur if the resistance of the regulating valve itself is low owing to excessive port area.

Either of these circumstances would result in the regulating valve being only partially open at full power, and a watchkeeper might well conclude that the feed-pump discharge pressure was excessive. His natural reaction would be to reduce this pressure by decreasing the compression on the feed-pump governor spring, both to achieve a small economy in steam and to increase the feed regulator opening, thus giving finer control of feed flow. Total system resistance would then be lower at any given flow, and K_s would be proportionately reduced.

Neglecting the accompanying slight alterations to other constants in equation 72, which applies to the Venturi-governed system, a reduction in full-load feed-discharge pressure from 650 to 608 lb/in² would reduce K_s from 61,300 to 35,600 lb/ft⁵ and the denominator would vanish, causing instability. The pressure-governed system, to which equation 71 applies, would remain stable by a large margin in the same or even in worse circumstances.

It must always be remembered that the departures from design calculated in the preceding paragraphs are those which would render the pump and discharge system unstable in isolation, irrespective of the characteristics of other components in the complete water-level-control loop. Owing to the phase lags introduced by these other components, ***the stability of the complete loop would be destroyed by smaller discrepancies than those calculated above.***

GENERAL CONCLUSIONS

1. Equations have been established which show the general trends of the behaviour of a boiler feed pump and its discharge system in response to movements of the feed regulating valve under normal operating conditions, provided that the boiler-drum pressure remains constant.
2. Systems with constant-speed or speed-governed pumps are inherently stable.
3. Systems with pressure-governed pumps may in theory be unstable but this is exceedingly unlikely with pumps of normal design.
4. Systems with Venturi-governed pumps are much less stable than the corresponding pressure-governed systems, and may contribute to instability of a complete automatic-control loop for boiler water level, a fact which must be weighed against the obvious advantages of this principle in other respects.
5. All systems are less stable at high than at low loads.
6. Corresponding theories can be evolved for the other components of the complete water-level-control loop, and hence for the loop as a whole, but will be valueless for quantitative design work until more experimental evidence is available on the transient characteristics of heavy steam-power-plant parts.
7. In assessing a control loop at the design stage, the effects of the possible off-design performance of major components must be taken into account.

End

SPOONER McLEAN FRENCH COOK GARTHWAITE
A $2·8m image

PEOPLE IN CONTROL

by Staffman

I was interested to learn that **G. M. E. Williams**, who is Head of the Department of Production Technology and Control Engineering at Northampton C.A.T., and **S. S. Carlisle**, Assistant Director of Bisra, are to represent the S.I.T. on the B.C.A.C. Williams was loath to comment on his appointment, but did say '. . . we must move extremely fast in this field, or be left behind'. In his *Viewpoint* last May, Carlisle lamented the time lag between technical feasibility and the actual amount of control equipment in industrial use, so they would both appear to hold similar views on the need for speeding up the industrial use of controls in this country.

There is aways a lot happening in the semiconductor world, so much so that it is difficult to keep up with the comings and goings within the industry. I gather that Dr **C. B. Mepham** has resigned from Associated Transistors (the tripartite firm owned by A.T. & E., English Electric and Ericsson), and that **E. Allard**, of English Electric Valve, will be Acting General Manager until a new appointment is made. Another change is at Semiconductors, **A. E. Underwood**, the Plessey director responsible for the company, having announced that Dr **J. Reekie**, is being detached for special duties and will be going abroad on behalf of Plessey; **G. W. Pratt** has been seconded by American Philco to act as Semiconductor's General Manager. At International Rectifier (G.B.)—the company jointly owned by Metal Industries and the American International Rectifier Corp.—the General Manager, **K. R. Simmonds**, has been appointed Managing Director. Simmonds, who was with Texas Instruments and, before that, with Elliott Brothers' Radar Division, visited International Rectifier, Los Angeles, in company with the manufacturing manager, **P. Ransome**, recently, in order to plan the manufacture in Britain of a further range of the American firm's devices.

Livingston Laboratories, the electronic instrument people, are, I gather, continuing to expand. They are moving to new premises at 31 Camden Road, London, N.W.1, on 4 April. Now the board is being enlarged. Headed by **F. Livingston Hogg** (Chairman and Joint Managing Director), the new board comprises **D. C. Rennie** (Joint Managing Director), Mrs **M. R. Hogg**, **H. Sellers**, **S. W. Urry** and **F. R. G. Webb**. Their expansion has also entailed a new post, that of Midlands Field Engineer, to which **Norman L. Glew** has been appointed.

I see that **J. W. Haig-Ferguson** has left Bruce Peebles to become Managing Director of R. & J. Beck. Members of the Griffin and George Group, Beck's have been manufacturing optical instruments and specialized scientific equipment for nearly 120 years. Haig-Ferguson was Divisional Director (Electronics) at Bruce Peebles, and responsible for their recently formed Electronics Division which covers industrial control systems and special-purpose electronic equipment.

There is a substantial (£1m or more) market for Marconi Instruments' X-ray image amplifier in North America, according to C. B. French, President of X-Ray and Radium Ltd, Toronto, who, in company with Vice-President and Sales Manager, H. M. McLean, visited M.I. recently. The Canadian firm are the American agents for this equipment, a device which presents the fluoroscopic image of the part under X-ray examination on television monitors. French believes that there is a North American market for well over a hundred machines. Clustered around the equipment in my photograph are, left to right, S. G. Spooner (Works Manager), McLean, French, **F. G. Cook** (Commercial Manager) and **E. Garthwaite** (Chief Engineer).

Essentially an engineer, but a good commercial man for all that, **Harry Williamson**, Managing Director of Fischer and Porter, Cumberland, has also been appointed Managing Director of the Dutch concern, Fischer and Porter (N.V.). I gather that the idea is to strengthen the co-operation between the British and Continental subsidiaries of the parent American flowmeter-and-process-control company. Williamson, who is 36, was Chief Development Engineer of Negretti and Zambra before joining F. & P. in 1957, and becoming Managing Director shortly after.

WILLIAMSON
key to six?

CANNON
key of door

R. B. Pullin's recently formed Process Control Division, which manufactures three different systems—the Pullin a.c. servo system, and the stepping-pulse and d.c. electronic systems designed in Italy by Officine Guardigli, is now managed by **C. H. Copley**. Until joining Pullin, Copley was in charge of the A.E.I. Instrumentation Division's Process Control Contracts group. Other Pullin news includes the appointment of **C. A. P. Cannon** to the board of Measuring Instruments (Pullin) as General Manager. Cannon has been with the company for 21 years.

A. B. Tilleray has been appointed by Thorn Electrical Industries to be Sales Manager of their Industrial Control

Division. Formerly with the Sorenson Division of J. Langham Thompson, Tilleray will now be responsible for marketing the electronic and electromechanical control equipment and systems manufactured by Nash and Thompson and the Electronics Division of Ferguson Radio.

R. J. F. Howard has been appointed Director of Marketing primarily concerned with the co-ordination of the sales activities of Metal Industries' electrical firms. Previously a director of Lancashire Dynamo Electronic Products, he remains a non-executive director of that company, and also joins the boards of Brookhirst Igranic, Lancashire Dynamo & Crypto, Foster Transformers, J. G. Statter, and Lancashire Dynamo Nevelin. Major **William Logan**, General Sales Manager of yet another Metal Industries firm, Avo, becomes Sales Director of Avo, and **E. F. Coppock** becomes Metal Industries' Group Financial Controller in succession to **P. Jardine**, who is taking up full-time directorships with J. G. Statter and Minerva Mouldings. Coppock has been budget officer with Plessey, financial and budgeting controller with Elliott Brothers and, until recently, financial manager of Evershed and Vignoles.

CAVANAGH FORRESTER
severing the connexion

I was saddened, if not really surprised, to see that Cannon Electric (Great Britain), the multi-point connector people, are now wholly owned by their American parent, Cannon Electric Co. (Los Angeles). Cannon connectors have been sold here since 1929 when **D. Forrester**, the retiring Managing Director, became the agent in this country. Forrester formed the British firm, in which American Cannon had a 25% interest, in 1953, but now that the American company has acquired the entire shareholding, he, his wife and daughter have retired from the board, although Forrester himself will act as a consultant to the firm for two years. **Robert J. Cannon** remains a director, and is joined by his brother, **James H. Cannon**, **Michel Bergerac** and **Edwin A. Cavanagh**, the new Managing Director. My photograph shows Cavanagh and Forrester exchanging share certificates and cheques on the occasion of the take-over.

AUTHORS IN CONTROL

J. Rothwell (*Controlling the big Australian radio-telescope*, page 84) joined A.E.I. (then called Metropolitan-Vickers Electrical), Trafford Park, in 1948 as a tester in the Electronics Department. He took his H.N.C. at the Royal Technical College, Salford, in 1952, and then transferred into the laboratory. In January 1955 he joined the Electronics Department's engineering staff, and has since worked as a development and project engineer concerned mainly with power servo systems.

G. B. Marson (co-author with I. C. Hutcheon—below—of *Electronics in industrial process control*, page 88) graduated in physics at Nottingham University in 1952, and joined de Havilland Propellers to work on instrumentation for missile guidance trials. In 1954 he joined the research staff of the College of Aeronautics, Cranfield, under Ministry of Supply extramural research contracts on wingbody interference and jet noise suppression. Since 1957 he has been with George Kent Ltd, and is responsible for the application and systems engineering of their electronic developments.

I. C. Hutcheon obtained a first in engineering science at Oxford in 1944, then spent four years with the Ministry of Supply on missile development, and six months at the National Physical Laboratory investigating stresses in aircraft structures. After a spell as Assistant Editor of *Engineering* he

MARSON

HUTCHEON

joined George Kent Ltd to work on the design of industrial instruments for measurement and control. He was appointed Chief Electronics Engineer in 1951, and has since been responsible for the development and design of electronic products.

Thomas B. Wearden (*Selecting small servomotors*, page 93) was at Manchester University (Faculty of Technology) where he graduated in 1951 with honours in electrical engineering. After service with the R.N.V.R. as an Electrical Officer, he joined Ferranti Ltd, Edinburgh, as a sales engineer and later worked in Ferranti's Computer Department as a development engineer on computer peripheral equipment. He joined Vactric (Control Equipment) Ltd as a senior sales engineer, responsible for the Midlands area, in January 1959.

W. G. Proctor (*Transient analysis of automatic controls*, page 96) read mathematics and engineering at St John's College, Cambridge. He was a college apprentice at Metropolitan-Vickers, Trafford Park, for two years and, on completing his apprenticeship, joined the company's Industrial Process Control Division. There he worked on the design and transient analysis of control systems, using both digital and analogue computers. He joined the United Kingdom Atomic Energy Authority in 1948, and is in charge of the analogue computing facilities in the Computing Section of Central Technical Services, Reactor Technology Branch.

K. C. Garner (*Controlling ballistic missiles*, page 102). See page 113, February 1961.

P. F. Blackman (*Pole-zero approach to system analysis*, page 105). See page 126, November 1960.

A. J. Morton (*Boiler feed discharge systems under changing load*, page 108). See page 126, November 1960.

A monthly review—under basic headings—of the latest control engineering developments for all industries; especially edited for busy technical management, plant and production engineers, chemical engineers, etc., who are not specialized in instrument and control systems

IDEAS APPLIED . . .

. . . to POSITION

Accurate displacement transducer with digital output

Systems for indicating and controlling the position of machine-tool mechanisms may usually be classified as either incremental (digital), or analogue. The incremental type, of which the moiré fringe method is a well-known example, has high potential accuracy, but depends on high-speed counting of the increments. A counting error at one point in an operation affects all succeeding measurements. Analogue

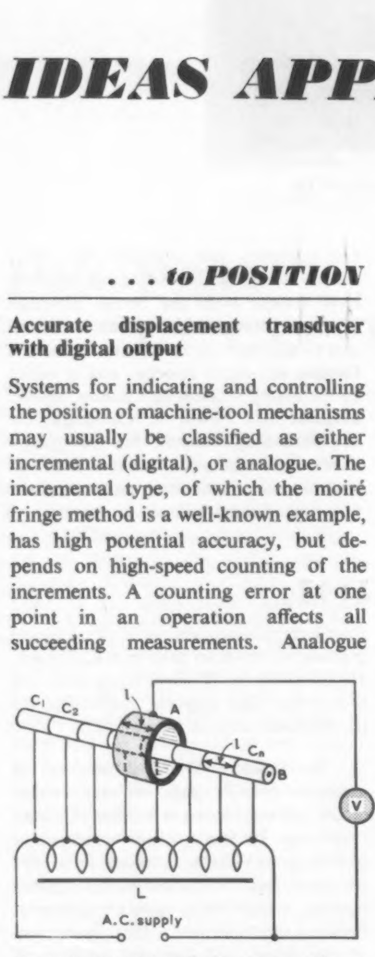


Fig. 1.1 Principle of linear transducer. (Actual connexions to the rod segments are internal, so that the ring *A* can move freely over the whole length of rod *B*)

systems do not have this disadvantage, but are generally difficult to manufacture to the accuracies now being demanded.

A new system developed by P. C. F. Wolfendale of Reilly Engineering combines incremental and analogue techniques, and is claimed to have the advantages of both, without their disadvantages. The principle of the Reilly measuring element is shown in Fig. 1.1. The rod *B* is made up of a number of cylindrical metal segments, or stators, $C_1 \ldots C_n$, accurately machined to a length *l*, and bonded together under pressure with a thin layer of insulation between them. These segments are each connected to tappings linearly distributed along the voltage divider *L*, which

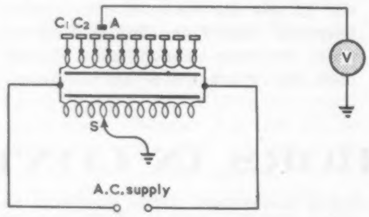


Fig. 1.2 Null-balance measuring technique incorporated in the system of Fig. 1.1

is energized from an a.c. source. A ring *A*, also of length *l* and concentric with the rod *B*, can be moved freely along the length of the rod. The voltage indicated on the meter *V* is then linearly related to the movement of *A* relative to *B*.

As so far described, the system is essentially analogue, and though it is dependent for its accuracy on the linear dimension of the segments, these are

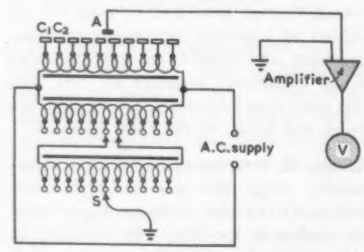


Fig. 1.3 Complete measuring system. Only two decade-tapped switches are shown; the number can be increased to give any required read-out accuracy

static units and can be manufactured to the same order of accuracy as slip-gauges.

Refinements are introduced into the basic system of Fig. 1.1 to give a digital output, independent of the calibration accuracy of the meter *V*. Reference to Fig. 1.2 shows how the system can be converted into a null-balance system, the meter *V* now being the balance detector in an a.c. bridge circuit. In the system shown, the earthed slider *S* may be adjusted until its position corresponds to that of *A*; the meter *V* will then indicate zero. The final stage is to replace the slider *S* by a series of cascaded decade-tapped windings, as shown in Fig. 1.3. For clarity, only two such units are shown in the diagram; the number used in practice depends on the accuracy required. The position of the decade switches under balance conditions gives a digital read-out of the linear movement of *A*. A final digit may be obtained by suitable calibration of the meter *V*, if desired.

There are a number of ways in which the system may be used. A dimension may be set on the switches and the head moved on the shaft until the meter reads zero; or the head or shaft may be moved, and the switches driven to the balance-point automatically, movement being indicated on any form of digital read-out device. The output of the bridge circuit, being phase-conscious and proportional to the displacement, is suitable for feeding to automatic positioning systems.

The accuracy obtainable depends on a number of variables, such as the total displacement being measured and the number of segments per unit length of

the rod B (Fig. 1.1). In general, accuracy improves as the length of segment is reduced, though this also increases cost of manufacture. A typical claimed accuracy is 0·0002% of the displacement, this being for a displacement of 10 in. The method may also be used for rotary motion, using sector-shaped 'stators'.

. . . to DENSITY

Measurement by resonating cylinder

W. E. ABBOTTS, The Solartron Electronic Group Ltd

There are at present few direct methods for measuring fluid density. A new method has been developed, using a resonating cylindrical probe immersed in the fluid, the resonant frequency being accurately related to the density. This system is expected to be suitable for most applications where a precise continuous measurement of density is required.

The principle of operation is simple. A bell, when struck, vibrates in many different ways or modes, and these modes have a different pitch or frequency, and die away at different rates. One of the most lasting notes is that in which the mode of vibration of the bell lip is as in Fig. 2.1.

A thin cylinder can be made to resonate in this way, and has the advantage over a bell that it can be reproduced more readily and can be maintained in continuous vibration by the method of Fig. 2.2.

The two coils A and B act as separate driving and sensing elements, and a miniature, encapsulated, transistor amplifier completes the feedback loop. Almost any 12-V supply powers the amplifier, and the consumption is below 30 mA. The frequency is read on a normal counter.

The medium surrounding the cylinder wall moves with it, and the more dense this medium is, the greater the mass that has to be moved. The medium-density thus contributes mass to the vibrating system with a resultant fall in frequency. The relationship between frequency and density follows closely to the form

$$(f_D/f_0)^2 = 1/(1 + D/K)$$

where f_D is the frequency at density D, f_0 is the frequency at zero density and K is a constant depending on the diameter and thickness of the cylinder wall.

Results indicate that the ideal law is very precisely followed, and accuracies of the order of 0·1% in the region of 1 g/ml should be realized in most applications.

Possible sources of error could be viscosity, non-homogeneity of the measured medium, corrosion, erosion, encrustation and temperature. A less predictable source of error is variation in pressure difference across the cylinder wall. Practical experience has shown that viscosity has little effect. Liquids of widely different viscosity (1 cS to 100 cS) lie sensibly on the same frequency/density curve. Gas bubbles affect the reading by change of density, which is the required effect, but excessive damping of the vibration due to energy losses akin to those used in ultrasonic cleaning can occur with certain bubble configurations. This will stop the vibration when the amplifier power becomes insufficient. In most cases, simple precautions can preclude this bubble formation in the vicinity of the cylinder.

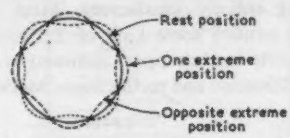


Fig. 2.1 Mode of cylinder vibration

Corrosion can be effectively combatted, as the cylinder can be made of any magnetic metal, and can be electroplated. Encrustation due to crystal growth, for example, and erosion by high-velocity solid suspensions, can be avoided in most cases.

A temperature coefficient of 0·01%/degC at 1 g/ml can be achieved, and operation over a wide temperature range is possible. Pressure differential also affects the frequency, and this can usually be overcome by exposing both sides of the cylinder to the same pressure. Alternatively, the pressure effect can be reduced by thickening the cylinder wall, as this effect varies roughly inversely as the cube of the cylinder thickness, whereas the density effect varies inversely with thickness.

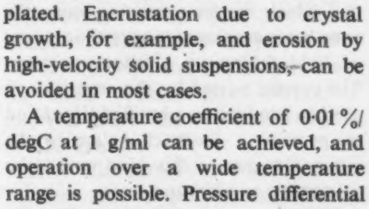


Fig. 2.2 Complete measuring unit

In appearance the transducer is a cylindrical probe of polished steel about 0·7 in diameter. The amplifier can be housed within the probe or separately, and the probe length, mounting arrangements and electrical connectors can be made to suit the application.

A very simple and rapid reading of density can be taken from the frequency counter display. The normal practice of a one-second count gives continuous monitoring of the density with an accuracy of the order of 0·1% of 1 g/ml. The resolution with a 10-s count is better than 0·01%. Control or recording can be accomplished, the complexity of the extra equipment depending largely on the accuracy required. Simpler read-out facilities are possible, but involve loss of accuracy. The frequency read-out lends itself readily to line or radio transmission with no added error.

Applications are foreseen in general wherever an accurate, remote indicating, rapid, robust and reliable transducer for density measurement is required. In particular aqueous solutions, oils, milk, beer, organic and inorganic solvents can perhaps be more conveniently monitored by this technique.

Acknowledgement

Acknowledgement is made by the author to the directors of the Solartron Electronic Group Ltd for their kind permission to publish this article.

. . . to LEVEL

Continuous measurement using gamma-ray source

Although radio-isotopes are widely used for level indication, most applications have been for liquids, usually employing a fixed source to give 'on-off' action of a warning or control system. An installation recently tested in a Czechoslovakian power station for indicating the contents of coal bunkers (*1*) uses a servo-operated moving source and detector to give a continuous indication.

The essential components of the arrangement are shown in Fig. 3.1. A cobalt-60 source of three millicuries activity is suspended in a steel tube passing vertically through the coal. Radiation from this source is detected by a halogen-filled Geiger-Müller tube suspended in a second steel tube about 2 ft away from the first, and connected to the radiation-intensity meter M by a tensioned cable. An output is taken from the meter M to a bridge circuit in the control unit C. When the source and detector are at the coal level, this bridge circuit is balanced, and no signal

is sent to the servo-motor *S*. If the radiation received by the detector is decreased because of source and detector being below coal level, the unbalance current in the bridge circuit initiates control action to drive the servo-motor *S* in the appropriate direction to restore balance. Similarly, a drop in coal level produces the reverse action. The system is said to indicate level with an accuracy of ± 1 cm, which is better than required in this particular application. A transmitter, which on the first installation was a simple sliding-resistance type, is driven from the servo-motor to provide remote level indication.

Advantages of this system for coal-level measurement are that it is unaffected by variations in coal quality, such as lump-size and moisture-content; it has no vulnerable parts inside the bunker liable to damage by falling coal; further, it can easily be adapted to detect cavities caused by 'bridging' of the coal. This latter function is important in the application for which the system was primarily developed, in which the bunkers are supplying automatically operated grinding mills, as 'bridging' can cause discontinuities in the supply. On the prototype there is no automatic provision for searching for cavities, but an overriding remote manual control is provided to allow the operator to 'scan'

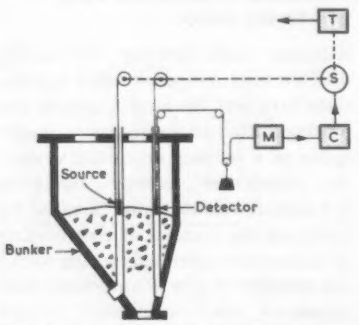


Fig. 3.1 Coal-level measuring system using servo-driven gamma-ray source

the whole depth of the bunker from time to time. It is proposed on future installations to have automatic scanning, operating at fixed intervals determined by a time switch. The feedback system will be disconnected during scanning (the indicator pointer remaining at the last measured value), and visual or audible warnings will be operated from the radiation-intensity meter.

Reference

1. Hudec, P. and Schiller, P.: *Automatizace*, 1961, *4*, (*1*, Jan.) pp. 16–17.

. . . to AMPLIFICATION

Photo-electric methods for small d.c. signals

Numerous systems have been used for amplifying small direct voltages, none being entirely satisfactory. Most systems employ some kind of d.c. to a.c. converter or 'chopper', followed by a.c. amplification and rectification. Methods of conversion currently in use in high-quality d.c. amplifiers mostly involve mechanical movement (e.g. the moving-contact chopper and the vibrating condenser).

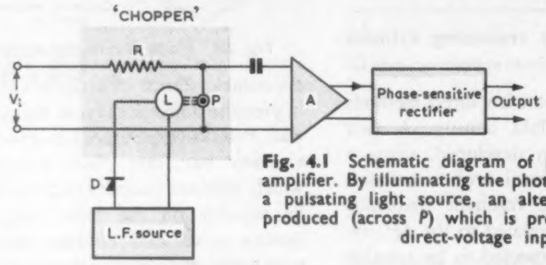


Fig. 4.1 Schematic diagram of photo-electric d.c. amplifier. By illuminating the phototransistor *P* from a pulsating light source, an alternating voltage is produced (across *P*) which is proportional to the direct-voltage input

Phototransistors have been employed for d.c. amplification in two basic ways. In one type, phototransistor circuits are used directly (i.e. without a 'chopping' stage) in conjunction with galvanometer movements: in this type of amplifier the signal current deflects a galvanometer coil which carries a moving vane, the vane being employed to vary the amount of light falling on a phototransistor. The current passed by the transistor is used to produce an amplified signal and to provide a feedback balancing the input. Systems of this kind tend to be susceptible to vibration.

The other type of photo-electric d.c. amplifier, which has been described by Draschev (*1*), incorporates a phototransistor in a novel form of 'chopper', followed by conventional a.c. amplifying and rectifying circuits, as shown in Fig. 4.1. The d.c. input is applied across the high resistance *R* and the phototransistor *P* (a cadmium-sulphide crystal). *R* is of the order of $10^9\Omega$, and the resistance of the phototransistor varies between about $10^7\Omega$ and $10^{11}\Omega$, depending on the amount of light falling on its. *P* is illuminated by a lamp *L*, which is energized from a low-frequency alternating source. A diode *D* is connected in series with the lamp, so that the light output of the lamp consists of pulses at the source frequency.

The instantaneous value of the input of the amplifier *A* at any time is $V_i R_p/(R + R_p)$, where V_i is the voltage input to the chopper, and R_p is the resistance of the phototransistor. Thus, using the approximate values of *R* and R_p given above, it will be seen that the voltage fed to the amplifier alternates between the approximate extreme values of $V_i \times 10^{-2}$ and $V_i \times 0{\cdot}99$. That is, the peak value of the input to the a.c. amplifier is closely equal to the measured voltage V_i, and quite large changes in the value of R_p at a given illumination (as might be caused by aging or temperature changes) will change this relationship only very slightly (e.g., a 100% change in the maximum value of R_p changes the a.c. input to the amplifier by less than 1%).

To ensure good signal/noise ratio, the amplifier *A* should have a narrow band-width. In (*1*) an amplifier of band-width 2 c/s (at -3 dB) was used, the frequency of the L.F. source being 22 c/s. Results obtained on an experimental apparatus showed linearity of better than 2·5% for inputs above 100 μV, and voltage drift within ± 15 μV over a period of 3–4 hours. It was the opinion of the author that these results could be considerably improved by refinements to the equipment, such as the use of overall d.c. feedback to minimize the effects of changes in the gain of the a.c. amplifier.

Reference

1. Draschev, M.: *Comptes rendus de l'Académie bulgare des Sciences*, 1959, *12* (*2*, March–April), pp. 101–103.

. . . to DIRECTION

Photo-electrically operated direction-sensitive relay

Detection of movement by interrupting a beam of light falling on a photocell or phototransistor is now commonplace. In a number of applications where this technique is used, confusion can arise because the object being detected is capable of reverse movement (e.g. the counting of articles on a conveyor, where the conveyor may be reversed.)

A photo-electric device has been designed by Elcontrol Ltd to eliminate

ambiguity in such applications. The device uses two phototransistors side by side and illuminated by a common light beam, as shown in Fig. 5.1. These phototransistors are connected into simple logic circuits which provide the desired result in the following manner.

The bi-stable circuits A_1 and A_2 give one of two possible outputs to the 'detector' transistors B_1 and B_2, depending on whether or not light is falling on the appropriate phototransistor. These signals will be referred to as the 'on' and 'off' signals respectively, and are applied to the collectors of the detector transistors. Further, when light falls on the transistor P_1 after a 'dark' period, a pulse is fed to the base of the detector transistor B_2. The circuit is arranged so that the relay circuit C_2 is operated only when a pulse from A_1 coincides with an 'off' signal from A_2.

Thus the relay circuit C_2 will be operated only when an object passes completely through the beam in the direction A_1A_2. Similarly, the relay circuit C_1 will operate when an object

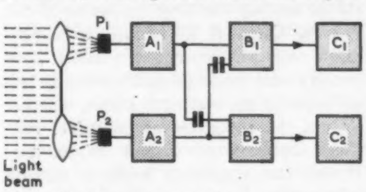


Fig. 5.1 Direction-sensitive arrangement of phototransistors. P_1, P_2 are phototransistors; A_1, A_2, bi-stable circuits; B_1, B_2, 'detector' transistors; C_1, C_2, bi-stable relay circuits.

passes in the reverse direction, so that the required discrimination is made.

An application in which this device has proved useful is that of detecting instrument-pointer movement on variable-area flowmeter systems, in order to obtain a signal for two-step control. The device ensures that the correct signal is given, even if the pointer reverses direction half-way through the beam, or is subjected to vibration.

. . . to THICKNESS

Control of coating processes using memory unit

The use of beta-ray sources for measuring the thickness of relatively thin sheet and strip material is now well established. In processes where a measurement of the thickness of a coating on such material is required, two heads are normally used, one before and the other after the coating device. The difference between the two measurements then gives the coating thickness accurately, irrespective of variations in the thickness of the base material, and the difference

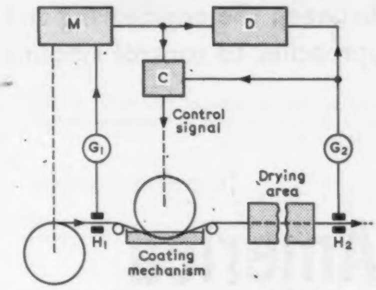


Fig. 6.1 Memory unit incorporated in coating-thickness control system

signal may be used to control the coating device. This method is satisfactory when the nature of the coating is such that its contraction during drying can be accurately estimated. In such cases, the two measuring heads can be placed close to the coating equipment, and the time taken for the material to pass from one gauge head to the next can be compensated for by variable integrator circuits in the gauge amplifiers.

A difficulty arises when the coating is such that its volatile losses during drying cannot be accurately predicted. In applications of this sort the second measuring head has to be placed after the drying oven, and the delay between the times when a given section of material passes the two heads may be several minutes.

Ekco Electronics have introduced a memory unit to delay the signal from the first measuring head in these applications. The general arrangement is as shown in Fig. 6.1. The gauges G_1 and G_2 give the instantaneous thicknesses measured by the heads H_1 and H_2, which are positioned to give, respectively, the base-material thickness and total thickness after drying. A signal from G_1 is taken to the memory unit M, which is mechanically coupled to the strip transfer machinery.

Low-leakage capacitors are used in the memory unit to store fifty separate readings from the base material. A rotary selector switch is synchronized to the transfer machinery so that the stored information for any particular section of the product is released when the section reaches the second measuring head. The signal from G_2 and the delayed signal from G_1 are fed to a duplex recorder D and to a comparator C, the output of which may be used to control the coating mechanism. Delays of up to five minutes can be accommodated by the system, and it is claimed that the signal loss during storage is less than 1%.

. . . to TEMPERATURE

Estimation of turbo-jet flame temperature

The combustion chamber temperature of turbo-jet engines is normally inferred from measurement of the tail-pipe temperature. This method of estimation tends to be unreliable when used with by-pass engines, because of the reduction of tail-pipe temperature caused by the by-pass air. It has been suggested that a temperature, T, representative of the flame temperature (i.e. corresponding to the tail-pipe temperature of an engine without by-pass), is given by the expression $T = a - n\,(b - 15)$ where a is the tail-pipe temperature, b is the intake temperature, and n is a constant for a particular engine.

By using specially made thermocouples, Sangamo Weston have produced a system which gives a direct reading of the required temperature. An averaging system of conventional (nickel - chromium / nickel - aluminium) thermocouples in the jet-pipe is connected in series with two special thermocouples in the air intake, as

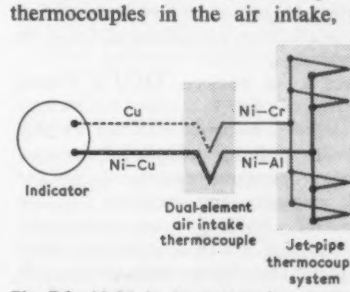


Fig. 7.1 Multiple thermocouple system for estimating flame temperature

shown in Fig. 7.1. The intake thermocouples, which are combined in a single sheath, comprise a nickel-chromium/copper junction, and a junction of nickel-aluminium and a specially developed nickel-copper alloy. This alloy gives a thermal e.m.f. against copper which is $(1 - n)$ times the thermal e.m.f. of the jet-pipe thermocouples, thus satisfying the law given above. It is claimed that the output of a system of this kind could be used as a control signal for fuel supply regulation.

This news-letter from our special correspondents in the United States includes a comparison between the engineering and physiological approaches to control systems

Look at America

Development in thin-film devices

The first commercially available digital computer with a thin magnetic-film memory was recently introduced by Remington Rand Univac (*1*). In addition to incorporating this new and advanced form of memory, the computer is completely transistorized. Tiny dots of Permalloy (only 1500 Ångströms thick), vacuum-deposited on a thin glass plate, comprise the thin-film memory. Only the control and arithmetic storage utilize this new memory, with 128 words of 36 bits available in 16 arithmetic- and 15 index-registers. Main computer storage is 8000 to 64,000 words of ferrite-core storage. Memory cycle time is only 0·6 μs for the thin films, compared with 4 μs in the core storage.

Not to be outdone, I.B.M.'s Federal Systems Division Laboratory has recently developed a cryogenic thin-film memory plane to perform sophisticated computer memory operations not presently possible with magnetic cores, magnetic tape, or drums (*2*, *3*). The postage-stamp sized plane consists of a 19-layer sandwich made up of 135 thin-film cryogenic devices, 120 of which are used to store 40 bits of information. Ten of the cryotrons are used for access to the stored bits of information and the remaining five permit the switching of bits of information from one memory plane to another. Each memory cell, consisting of three cryotrons, combines storage with an elementary logic function. Because of this combination of functions, it is expected that one use of the device may be in an 'associative memory', which simultaneously searches all memory registers and thus speeds access to stored information. Development of successful techniques for the accurate duplication of of these devices in large quantities has probably been the key to this major advance in cryogenic devices.

THIS MONTH
Thin-film memories
System dynamics
Control technology and physiology

Newest among the thin-film devices is an experimental cryogenic device that uses the electron tunnelling phenomenon in a superconductive state (*4*). Under development at General Electric's Research Laboratory in Schenectady, N.Y., the new device consists of two metallic films separated by a very thin insulating layer. When a potential difference is applied across the two metallic films, a current flows (or actually electron-waves tunnel) through the insulating layer. If the films are maintained at temperatures in their super-conductive state (about 1°K) an *S*-curve relationship between current and applied voltage results. The device thus exhibits a negative resistance region similar to that found with tunnel diodes.

Unlike the tunnel diode, this new cold tunnelling device apparently could be rather simple and inexpensive to fabricate. One particular experimental device consisted of an aluminium film and a lead film on opposite sides of a thin glass slide. The two one ten-millionth of an inch metallic films were formed by evaporating the metals onto the glass. According to G.E. experts, the device has potential as a cheap bi-stable element that could be used as a switch, diode, triode, resistor, or capacitor. The frequency of operation of the device seems to be limited mainly by its capacitance. Time constants on the order of 10 mμs have been predicted. The need for a suitable cooling system to achieve the near absolute zero conditions remains somewhat of a problem. Dr Guy Suits, G.E.'s Vice-President and Director of Research, says that a suitable cooling system can now be made to occupy only one or two ft³.

Rapid look at system dynamics

Determining the nature of the roots of the characteristic equation of a linear system can, of course, be extremely useful in finding the time response of the system. Often it is helpful to simply know whether or not the roots have positive real parts (Routh's stability criterion) or, if the system *is* stable, whether or not the roots are all negative, real. (Such systems are called monotonic.) If this last condition holds, a method exists that allows a rapid and accurate estimation of the system transient response (*5*). This reference also presents an explicit procedure, similar to that of Routh's criterion, for learning whether or not all roots are negative, real. The application of either procedure is straightforward, but does involve the successive evaluation of determinants whose orders go from 1 to n, where n is the order of the system. Hence the procedures, though straightforward, may be tedious.

An extremely simple 'necessary' condition for the presence of a monotonic system has been worked out by Hakimi (*6*). If a characteristic equation of the form

$$a_n s^n + a_{n-1} s^{n-1} + \ldots + a_i s^{n-i} \ldots + a_0 = 0 \qquad (1)$$

has only real negative roots, then the conditions

$$\left.\begin{array}{l} a_i \leqslant a_{i-1} \\ a_i \leqslant a_{i+1} \end{array}\right. \qquad 0 < i < n \qquad (2)$$

cannot be simultaneously satisfied.

Therefore, if inspection of Eq. (1) shows that Eqs. (2) are simultaneously satisfied for some value of i, then the

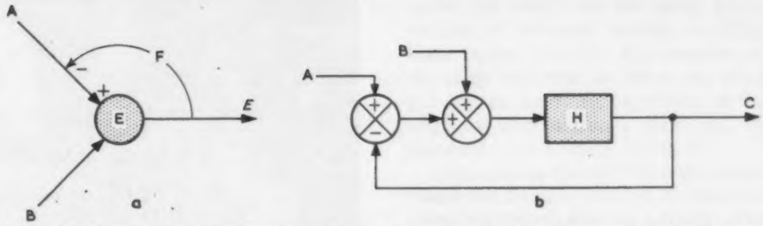


Fig. 1 Comparison between biochemical and control engineering notations (a) Physiological notation: A and B, factors; E, effector; E, effect; F, feedback. (b) Engineering notation: A and B, inputs; H, process; C, output

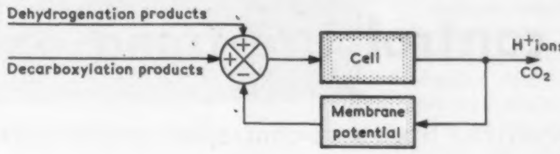


Fig. 2 Typical example of a physiological process with negative feedback, i.e. functioning 'in constancy'

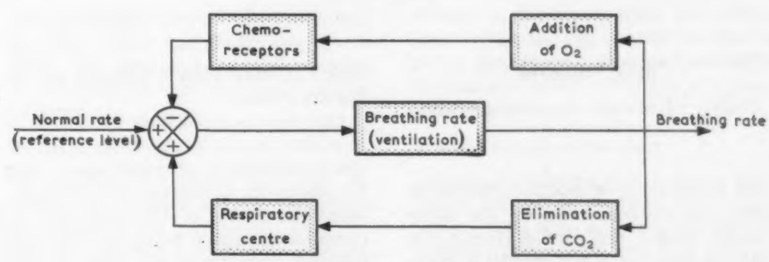


Fig. 3 Regulation of breathing-rate

system cannot be monotonic. If Eqs. (2) are not simultaneously satisfied, then it is possible that the system may be monotonic, and it may be of advantage to apply the explicit test of reference (*5*) to find whether or not this is the case.

A similar 'necessary' condition exists for the stability criterion. If Eq. (1) has no roots with positive real parts, then the conditions

$$\begin{aligned} a_i &\leq a_{i-2} \\ a_i &\leq a_{i+2} \end{aligned} \qquad 0 < i < n-1 \qquad (3)$$

cannot be satisfied simultaneously. Hence, if inspection of the coefficients of Eq. (1) reveals that Eqs. (3) are simultaneously satisfied, the system is unstable. If Eqs. (3) are not satisfied, the system may or may not be stable, and Routh's criterion should be applied.

Control technology and physiological systems

The use of block diagrams and so-called 'signal-flow graphs' has long been useful as an aid in visualizing and analysing physical systems. An extension of the application of this technique to physiological and biochemical systems is presented by Laborit and Weber (*7*). Unfortunately, much of their nomenclature, having been carried over from biochemistry, is different from that of control engineering, and the same is true of some of the diagrammatic conventions. This is illustrated in Fig. 1.

When negative feedback is present, the system is said to operate in 'constancy'; when the feedback is positive, the system operates in 'tendency'. Unlike most physical systems, positive feedback is very commonly found in many physiological processes. Of course, it must be realized that the convenient simplification of linearity is not realistic enough to be useful in most cases, hence the very general classifications of operation in constancy and in tendency. There is in all cases a quite definite range of values that the variables must stay within under normal conditions. If a variable is forced out of its range by unusual environmental changes (such as disease, or extreme physical exertion, etc.) the *modus operandi* of the organism for the control of its internal processes will change. Thus we have here a semblance of 'dual-mode' control.

Control of a specific physiological process is shown in Fig. 2. In the presence of oxygen, a cell tends to produce H ions and CO_2. The inputs to the cell are the products of dehydrogenation and decarboxylation processes (metabolism). The availability to the cell of these products is controlled by the permeability of its membrane, which in turn is controlled by the concentration of the H ions and CO_2. It should be noted that the principal application of the signal-flow concept, on the fundamental level, is to physiological *mechanisms* (e.g., the regulation of H+ concentration), rather than to specific *parts* of the physiology, such as the complete destruction of a cell. Fig. 3 shows the rather well-known interaction between breathing rate and the relative levels of CO_2 and O_2 concentration in the blood.

Owing to the fact that control of a multiplicity of variables plays such an important role in physiology, the concept of seeking the mechanisms involved in each process has become one of this field's underlying philosophies of investigation. The block diagram allows a useful topological representation of these separate mechanisms, but more importantly, allows their interaction upon each other to be easily depicted. In this way the elementary processes can then be combined—ultimately to the level of the complete organism. As mathematical description of the elementary processes improves, the eventual outcome of this type of analysis might be computer 'modelling' of human physiology, or at least certain aspects of it such as behaviour during disease or under other unusual conditions.

Your American Correspondents

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New computer languages

Control learns that a new computer programming technique, called 'Gecom' (general compiler), which automatically translates English instructions into computer code, has been introduced by U.S. General Electric. With this technique a computer can accept 'Cobol' (common business oriented language) and 'Algol' (algorithmic language). Primarily an automatic coding technique, Gecom enables the computer to receive English words and phrases, translate them into machine directions, and define computer operations for solution. It is claimed to eliminate much of the specialized and technical training previously required by computer programmers. G.E. have also recently introduced a new method of English-language instruction to computers, called 'Tabsol' (tabular systems oriented language), which is said to be another step toward a language for all computers which can be read both by human beings and by the machines.

Dunlop control tire-tread extrusion

Higher productivity from auto-controlled tandem extrusion line at Fort Dunlop

by E. Holroyd

Manager, Equipment Department, Dunlop Rubber Co. Ltd

THE PRODUCTION OF SHAPED LENGTHS OF tire-tread rubber, each of the same weight, length, and profile, from a hot plastics material, is not easy. It is, however, most important that this ideal constancy of product should be approached as closely as possible. If, for instance, the tire builder finds that his lengths of tread are too short, he has to stretch them to make the lengths fit the casings, and the tread will be thin in places and out of balance. Even if the lengths are accurate, their weight and thickness may vary.

Basically the process consists of extruding hot tread-compound through a die to give it the required shape, but the tread may not always be extruded at a constant speed. If the take-away conveyor happens to be running slightly too fast for the extruder, it will stretch the softened rubber and distort it so that the treads, although cut to the same length, may be of different weights. A more significant effect is that internal stresses may be introduced and so alter the length of tread while it is on the way to the tire builder.

One way to avoid these conditions is to make the take-away conveyor follow every variation in extrusion speed, and for successive conveyors to follow the speed variations of the first one. A complication stems from the fact that different compounds are used for the centre section and the two sidewalls so that two extruders are necessary, the sidewalls being joined to the centre section 'on the run' at the consolidating conveyor. It is necessary, therefore, to match not only the extruder speeds but also the take-away conveyor speeds. This is, in fact, what is achieved on Dunlop Rubber's recently commissioned tandem extrusion line at Fort Dunlop.

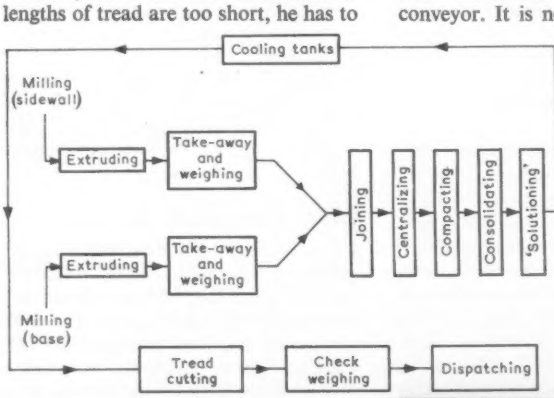


Fig. 1 (left) Basic sequence of operations. Note that the 'sidewall' and 'base' production lines are separate, and it follows that extruder speeds and take-away conveyor speeds must match

Fig. 2 (below) Rubber emerging from the die drives a photo-electric tachometer giving a speed-control signal for the take-away conveyor

The tandem extrusion line

The general sequence of operations will be apparent from the simplified diagram, Fig. 1. The base tread runs from the extruder over a continuous-weighing conveyor and thence, *via* compacting, consolidating and 'solutioning' conveyors, to cooling-tank conveyors, these latter consisting of several water tanks in series. From the cooling section, the tread runs to the flying shear cutter where it is cut up into lengths.

The sidewall treads run from their own extruder, *via* a weighing conveyor, to join up with the base tread of the consolidating conveyor and thence on to the cutter.

Speed control

The two extruders are each driven by a 150-hp d.c. motor having constant shunt-field excitation from metal rectifiers, and speed control by variation of the armature voltage. Each motor is fed from the 440 V a.c. mains supply *via* a grid-controlled rectifier equipment consisting of six single-anode mercury vapour rectifier bulbs, which are bridge-connected.

Speed control of the extruder motors is by means of manually operated potentiometers, speed-holding being achieved with a d.c. tacho-generator directly coupled to the non-driving end of each motor. Once the speed of an extruder has been set, it is held there, within close limits, automatically.

As the rubber emerges from the extruder it drives a roller positioned close to the die-mouth (Fig. 2). Attached to

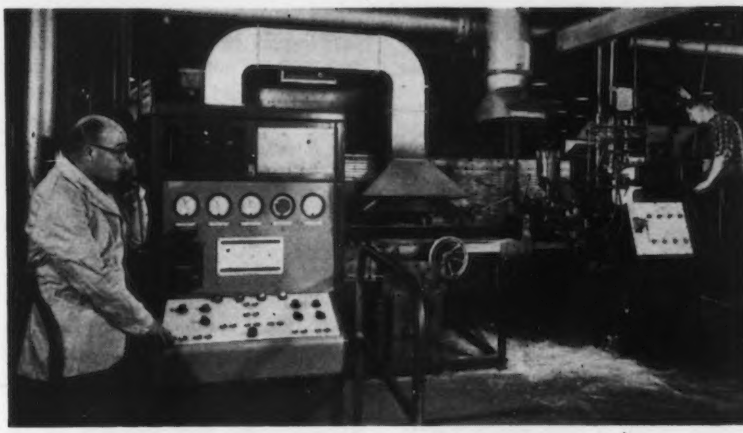


Fig. 3 View near die-mouth of tandem extrusion line

the roller at one end, and driven by it, is a metal disk having accurately spaced slots machined at its periphery. A light source and photo-transistor are mounted relative to the disk so that, as the roller is driven by the material, the apertures in the disk allow the photo-transistor to be illuminated momentarily. As the material moves forward, a series of square pulses is generated by the photo-transistor, the frequency of the pulses being directly proportional to the speed of the material. This variable-frequency signal is converted into the proportionately variable d.c. voltage which controls the speed of the d.c. motor driving the take-away conveyor (Fig. 3). Thus the conveyor follows automatically the speed at which the rubber emerges from the die.

In practice, this signal provides a reference voltage for all the conveyor-driving motors, every conveyor responding to any change in the speed at which the tread emerges from the extruder and the tacho-roller. A 'manual-auto' switch permits a line-speed reference voltage to be obtained from a manually operated potentiometer.

Each conveyor is driven by a d.c. motor having constant shunt-field excitation and variable armature-voltage speed control. The variable d.c. supply is obtained from the 440-V 50-c/s mains, *via* grid-controlled thyratron valves. Two sizes of driving motor only (2 hp and 5 hp) are used and, in order to ease maintenance, similar chassis for all electronic control units are used throughout, and one size of thyratron, the only difference being that two valves and three valves are used in parallel for the 2 hp and 5 hp drives, respectively.

Each conveyor motor has a d.c. tacho-generator attached to the non-driving end for speed holding and stability. Speed trimming of the order of 10% is provided by dancer-roller-operated potentiometers (Fig. 4) which are positioned between conveyors, and so control the succeeding conveyors. Thus the tread is permitted to relax between conveyors and find its own level of speed.

Position control

A photo-electric device has been developed to position the sidewalls on to the centre tread accurately. This centralizes the centre tread and then ensures that the sidewalls maintain a constant track automatically.

Two photo-cell and light-source assemblies, positioned one on each side of the tread, are moved by left- and right-hand threaded coupled lead-screws, in such a way that they are always equidistant from the mid-point of the conveyor line. The photocells pick up the edges of the centre tread, and any out-of-balance signal is fed to a servo-motor which rotates a shaft placed laterally under the tread. On the shaft are a number of ball-race bearings on skew brass bushes (Fig. 5). Any rotation of the shaft will tend to move the tread one way or the other, depending on the angle of the bearings. This will be apparent from a study of Fig. 6.

Fig. 4 Cooling tanks. Note dancer roller which operates a potentiometer to control speed of succeeding conveyor

After passing through the water tanks, where the tread is allowed to relax between sections as it cools, a flying cutter cuts it into accurate preset lengths. This tread cutter is a flying-shear rotary-blade cutter of novel design.

Accurate tread-lengths are determined by a continuously measuring three-stage Dekatron device, which receives its impulses from a photo-electric pulse generator similar to that controlling the speed of the take-away conveyor, the slotted disk being driven by a roller resting on the tread. Each slot represents 0·1 in and the operator is able to preset the required length of cut tread by means of selector switches at a control desk.

A more consistent product

As a result of these controls, a more consistent product is produced at a much higher speed than has been permissible hitherto. Production speeds as high as twelve cut treads a minute are already possible, and it is anticipated that this figure will shortly be increased to fifteen a minute, with a corresponding line speed increase from 48 ft/min to over 60 ft/min.

Fig. 5 Skew-bearing centralizing device which positions the sidewalls accurately with respect to the tread

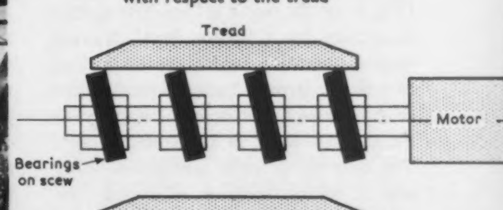


Fig. 6 Any out-of-balance (off-centre) signal controls a servo-motor driving a shaft to give left- (top) or right-hand bias (below)

Canberra's auto-electric steering control

P. & O.-Orient liner has automatic steering under gyro-compass control

THE 45,000-TON SHIP, S.S. *Canberra*, built for the P. & O.-Orient Lines by Harland & Wolff, and now completing her fitting out, has a great deal of equipment of control engineering interest aboard, possibly the most obvious example being the automatic steering arrangements. Produced by S. G. Brown, of Watford (now a member of the Hawker Siddeley Group, through the controlling interest held by de Havilland Aircraft), the installation consists of an Arma-Brown transmitting gyro-compass feeding an 'auto-electric' steering control system.

Three methods of steering

In *Canberra*, the auto-electric system provides three methods of steering control from a single steering column (Fig. 1) on the ship's bridge. The rudder is applied by a Brown Bros' steering engine operating under the control of two S. G. Brown 'after power units' (Fig. 2) which are coupled directly to the control valve of the steering gear. The after power units themselves—only one of which operates at a time, the other being in the stand-by condition—are primarily controlled from the steering column on the bridge.

The three methods of steering control provided by the bridge unit shown in Fig. 1 are: 'main', or hand-electric, control by means of a handwheel; 'secondary' hand-electric control using a lever on the front of the bridge unit; and 'auto' control which employs a directional control element, or 'brains' unit, operated from a datum provided by the gyro-compass.

Using 'main' control, manual movement of the handwheel operates port and starboard switches which, in their turn, operate breaker switches governing the field of the motor driving whichever power unit is in use. Handwheel steering is of time-base rather than follow-up type, that is, the port—or starboard—switch remains closed, and the rudder continues to move, for as long as the wheel is held over. On centralizing the wheel, the switch opens and the rudder is halted in position. Secondary—manual lever—control operates similarly: when the lever is moved to port or starboard, switches are made which operate a second system of breaker switches and so govern the motor field of the other (stand-by) after power unit. On 'auto'—automatic steering—the 'brains' unit provides a signal to operate breaker switches controlling the field of the same after power unit as that used for 'main' control.

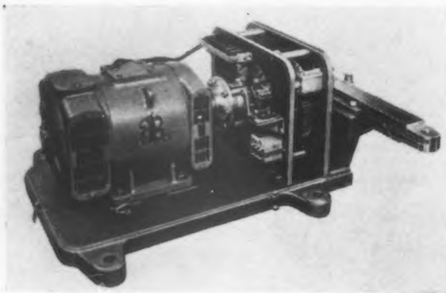


Fig. 1 (left) *Canberra's*' auto-electric' automatic helmsman

Fig. 2 (below) After power unit for control of steering engine

There are, therefore, two completely separate operating circuits, one of which can be used, for instance, for 'main' and 'auto', and the other for 'secondary' control. There are two separate power supplies from the ship's mains; if one should fail this is indicated by an alarm, and the other switched into circuit.

The bridge unit incorporates an indicator showing the amount of rudder-movement transmitted to the steering engine by the after power units (a separate rudder-angle indicator on the bridge, and driven by a transmitter mechanically coupled to the rudder post, shows actual rudder position), a course trimmer to permit small alterations of course to be made when steering under automatic control, rudder and weather controls which may be adjusted in order to offset particular conditions of wind and weather, and a compass repeater.

On the deck aft, above the steering engine compartment, is a separate electric steering control equipment which is intended for emergency control of the after power units. This provides two separate methods of hand-electric steering—handwheel and push-button—and operates similarly to the bridge unit. It has its own independent breaker switches for control of the after power units.

A rudder-angle transmitter on the rudder post itself, feeds back data on rudder position to rudder-angle indicators on the bridge, and in the engine room.

Automatic steering

The directional control element, or 'brains' unit which, operating in conjunction with the master gyro-compass, provides automatic steering with economic use of the rudder, has been used by S. G. Brown in much the same form for very many years. *Canberra*'s automatic steering system is shown diagramatically in Fig. 3, and the 'brains' unit in Fig. 4.

In operation, the gyro-compass provides a datum indicating any deviation of the ship's head from course. The resulting error signal is transmitted in step-by-step form to a small motor in the 'brains' unit, called the compass motor. The latter is connected through differential gearing to a contact drum, so that the drum may be driven round

by an amount proportional to the error. The drum is made up of copper segments insulated from one another, and attached to its axis is a bracket carrying two sets of roller contacts (trolley roller contacts) which are free to revolve around the drum.

Assuming that the ship has veered to starboard, the compass motor will turn the drum so that the port trolley-contact will connect with the port contact-segment of the drum. The circuit thus made will energize the port trolley coil—an electromagnet—and so cause the whole contact-roller assembly to rotate to port.

Simultaneously, this drum-to-roller contact will complete a circuit through the operating coils of the port breaker switch, so energizing the field circuit of the particular after power unit in use. The latter will apply port rudder to correct the ship's heading and, in so doing, operate a feedback transmitter. This sends a step-by-step signal to a feedback motor connected to the opposite side of the differential to that driven by the compass motor. The drum is, therefore, repositioned, bringing the trolley contacts back on to the insulated section of the drum, and so halting further rudder movement.

As the ship answers the helm and veers to port, heading information from the compass operates the compass motor again, repositioning the contact drum once more, but in the opposite direction so that the other (starboard) trolley contacts the drum. The other electromagnet is energized and rotates the contact trolley assembly in the opposite direction, the other breaker switch making and starboard rudder being applied. In this instance, the trolley assembly rotates twice as far as before.

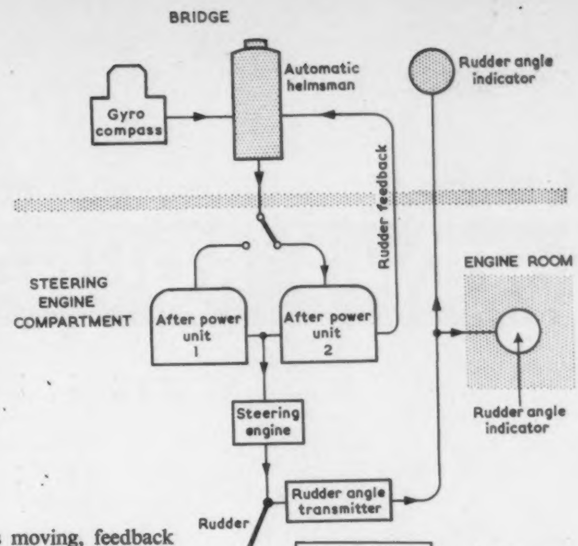


Fig. 3 (right) Automatic steering arrangements in *Canberra*. Error signals from the gyro-compass are fed to the automatic helmsman which drives the after power unit controlling the steering engine and, thus, the rudder

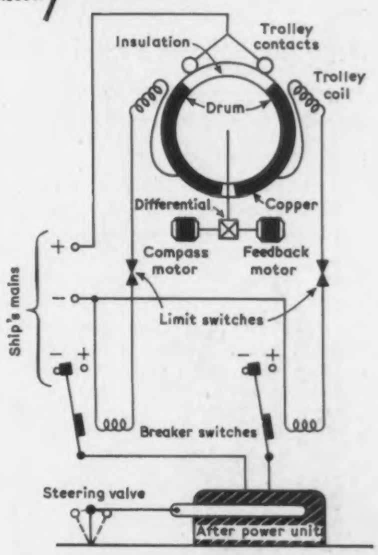


Fig. 4 (below, right) In the directional control element ('brains' unit) 'compass' and 'feedback' motors are fed with error and rudder-position information and operate in conjunction to position the drum

While the rudder is moving, feedback again repositions the drum and the cycle continues.

Adjusting the system

In this way the 'brains' unit arranges a cycle of rudder movements to keep the ship on course. However, the optimum amplitude and frequency of rudder movements depend mainly on weather conditions, so there are two controls, known as 'yaw' and 'rudder angle' adjustments, which enable the deck officer to vary the cycle to suit these conditions. For instance, in a heavy sea on the quarter, the ship is usually allowed to yaw a certain amount before rudder is applied, while in calm weather the rudder angle can be greatly reduced.

The yaw allowance is determined by the angle through which the drum can turn before contact is made at the trolleys. For example, if a large yaw-setting is chosen, the trolleys are brought close together. The rudder angle adjustment determines the amount by which the trolleys are pulled over when they contact the copper conducting-strip on the drum.

CONTROL IN ACTION

Magnetic compass steering

NOW UNDERGOING FINAL TRIALS IN Vosper's *Sea Victory*, a converted naval motor launch, is Sperry Gyroscope's new 'magnetic compass pilot'. Designed to provide automatic follow-up steering control for the smaller vessel which has no gyro-compass, this inexpensive system consists of a conventional magnetic compass, a detector unit, an amplifier and a power unit.

The basic reference is, of course, a 6-in liquid-filled magnetic compass, and the detector unit is fitted over its bezel ring, although the compass can still be used for manual steering. The detector unit has a course selector dial, graduated 0 to 360°, and the desired course is set up on this dial. The detector consists of a magnetic flux valve of 'Y'-shape, which is excited at 400 c/s, and incorporates a pick-up coil. If the ship goes off-course, the resulting change in magnetic flux from the compass card is detected by the pick-up coil. The error signal derived in this manner is fed to an amplifier panel.

Here the direction and amplitude of the off-course signal are determined, and caused to operate contactors controlling the ¼-hp motor of the power unit. The latter drives the normal manual steering system through a sprocket-and-chain arrangement.

The amplifier panel contains a transistor amplifier of printed-circuit type, and carries a three-position switch. This permits one of three steering methods to be used: 'hand' or remote control; 'auto'—automatic control, and 'off'—manual steering. Rudder and weather adjustments to suit the particular ship and the state of sea are also provided.

NEWS ROUND-UP

from the world of control

— COMPUTER CONTROL —

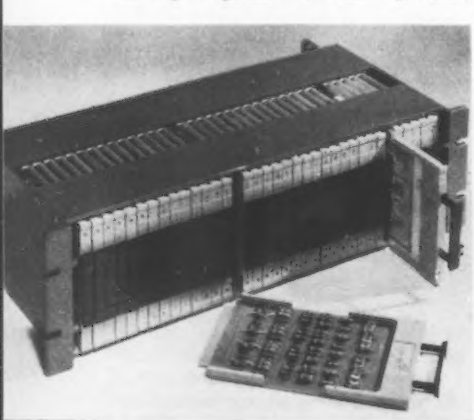
Argus for Babcock's and I.C.I.

Ferranti's process control computer

At a press conference last month in the new offices of Ferranti's London Computer Centre (Newman Street, London, W.1) their Argus digital automatic control system, ordered by I.C.I. and Babcock & Wilcox, was unveiled.

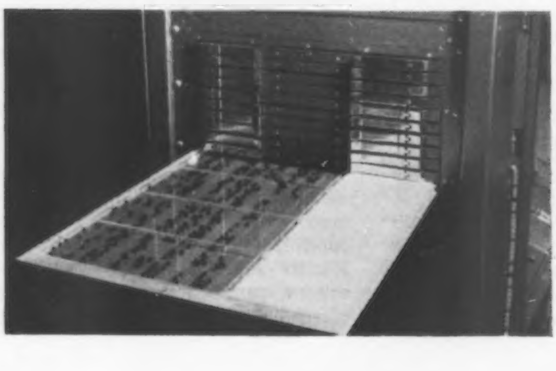
Argus is a digital computer for automatic control, which can carry out a variety of operations, the following being typical: sequence switching and logical decision in, for example, a complicated start-up sequence or batch process; the measurement and conversion of many variables for control or monitoring purposes; the programmed operation of control valves or switches, or control by the assessment of measured variables—either directly or indirectly by, say, the adjustment of set-points; data logging by either continuous sampling, or if some variable falls outside specified limits; the assessment of plant conditions from the state of measured variables in order to obtain a 'figure of merit'. This latter operation could provide a control function to maintain a preset condition, or form part of an optimization routine.

The equipment has been designed as a number of basic elements which can be assembled together in order to suit a particular application, is sufficiently flexible to suit changes in operating technique, and is claimed to be extremely reliable.



Standard circuit elements

The circuit elements of the machine are built on standard printed-circuit cards, each of which contains several similar elements, and solid-state components are used. These elements consist mainly of standard 'nor' gates performing switching functions, and flip-flop stores holding transient information. Thirty-six cards are plugged into a standard box which contains the interconnecting wiring. This wiring employs the wrapped-joint technique, rather than conventional soldering.



Above left, printed-circuit packages, plugged 36 into a box, make up Argus's circuitry

Ferranti's Argus process control computer is programmed by inserting pegs of ferrite material into holes drilled in printed circuits, so coupling the circuits magnetically. Here is a program on one of the sixteen trays

Magnetic plugboard programming

The program store is rather unusual in that, although the program is plugged-in in conventional fashion, the plugs themselves are of ferrite material, and give magnetic coupling between circuits printed on a plugboard. In this way, instructions are maintained in permanent form during the running of the process, although changes can be made fairly easily by rearranging the plugs.

The program is held in plugboard trays, each containing 64 instructions. An instruction requires 25 binary digits, each digit being allocated a hole in the tray, and is formed by inserting a magnetic plug in the appropriate hole to represent 1 and leaving the hole empty for 0. A system of say 1000 instructions would occupy sixteen trays.

Core store

A ferrite core matrix, which allows immediate access, holds the values of measured variables, output information, and derived variables for future calculation. The standard unit will hold 1024 twelve-bit words. As direct access is available to and from external equipment whenever the store is not in use for the main program, control and logging may be independent.

I.C.I.'s Argus

The system ordered by Imperial Chemical Industries is intended for the direct control of a chemical plant at Fleetwood, Lancs. It appears that when the installation of new instrumentation became necessary, it was decided to centralize all the control loops in a digital computer, rather than to install a large number of individual analogue controllers in a conventional system. The price—a large Argus control system would cost between £50,000 and £100,000, or more, depending on the peripheral equipment—of the I.C.I. system is said to be slightly higher than that of a conventional analogue system. However, the benefits from computer control outweigh the cost.

The process variables will be logged on magnetic tape so that the plant characteristics can be analysed on a Ferranti Mercury computer. Process data gained in this way will eventually be incorporated into the Argus program so that, ultimately, the independent control loops will be supervised by a master section of the program.

The machine will not optimize the process, but instead replace 100 individual control loops. It has a program capacity of 1024 instructions and 1024

words, and over 300 analogue signals of six different types are to be fed in, one group of 100 points being selected in 1/16s. The machine will provide outputs for controlling nearly 100 pneumatically operated valves.

Babcock & Wilcox's system

I.C.I. were particularly secretive about the use to which they intend putting their machine, pleading, as is their usual wont, 'commercial security'. Babcock & Wilcox, however, were much more forthcoming. Their Argus will control the start-up and shut-down of a 200 MW boiler in the C.E.G.B.'s new station at West Thurrock.

Receiving data from conventional instrumentation, the system will perform all preliminary checks, and then start up individual items such as fans and coal pulverizers. Meanwhile, it will adjust the set-points of the analogue controllers to bring the boiler up to load as quickly as possible, whilst maintaining various limits such as those concerned with metal temperature.

The program store will hold 4096 instructions and the working store, 1024 words. The input equipment will accept up to 171 analogue signals from 97 transmitters and 32 three-term controllers. In addition, digital signals will be accepted from 675 on/off devices, and readings from 150 thermocouples will be selected for checking metal and bearing temperatures. The output provides digital drives to about 150 contactors, for controlling motors, etc.

Monitoring and logging will be carried out by two printers: an operations printer will provide details of computer operation and plant behaviour; the other will print boiler temperatures, pressures, etc., at intervals, and also give figures for the plant's efficiency and performance. Apart from its control and data-logging functions, the computer will monitor all essential alarm points and operating equipment.

Control understands that the Babcock Argus is not expected to result in any saving in costs. The intention is to provide the best start-up every time, something that the complexity of the task makes impossible under manual control.

Anatrol at Warren Spring

The de Havilland analogue computer controller which, it will be recalled, employs a switching arrangement in order to economize in the number of amplifiers used, is about to undergo trials at the D.S.I.R.'s Warren Spring Laboratory. There it will provide feed-forward control of a binary distillation column. The column will be subjected to disturbances in the composition and flow of the feedstock, the disturbances being measured and fed to the computer which will adjust the values of reflux flow and boil-up flow. In this way it is hoped to achieve the desired control aims with regard to the product of the column. It is intended to regulate the composition of the top and bottom products. Alternatively, Anatrol will regulate the composition and flow of top and bottom products, or control their production to a given composition with maximum possible flow.

It is understood that these trials should be complete in August, and that two commercial Anatrol installations are now being negotiated.

Optimat at Coryton

The Elliott-Automation digital optimizing controller, Optimat, has now been delivered by Panellit to Mobiloil at Coryton, and is being commissioned preparatory to commencing full-scale trials. As mentioned in these columns last October, this computer is to control a distillation column in order to obtain the maximum output of product without any loss of product quality.

—— DEFENCE ——

A stand-off capability

The *Report on defence 1961* (H.M.S.O.), contains little that is new, and nothing unexpected. For example, 'The Soviet fleet of submarines is of great size. Mr Khrushchev has claimed the possession of nuclear submarines. We must expect the number of these to increase and that they will carry nuclear missiles . . .'

Mk II V-bombers are to '. . . be given an increasing stand-off capability . . . . The missiles which carry the British-made warhead . . . . must be of such a type and characteristics as will present the greatest diversity of attack.' The agreement to provide facilities for a depot ship and floating dock in Holy Loch for U.S. Polaris submarines is mentioned, as is the fact that a surface-to-air *Bloodhound* missile costs £35,000, although a salvo of two can destroy an aircraft.

Royal Navy

The *Explanatory statement on the Navy Estimates 1961–62* (H.M.S.O.) is more interesting, if nearly as evasive. A further two guided-missile destroyers are to be built—four are already under construction—and these ships will have the beam-riding *Seaslug* medium-range guided-weapon system, and the shorter-range *Seacat* anti-aircraft missile system. The first of the class, H.M.S. *Devonshire*, should be complete by the spring of 1962. Trial firings of *Seaslug* have been most successful. An improved Mark II version, of greater range and speed, is being developed and will be fitted in the two latest guided-missile destroyers. *Seacat*, which is to become the standard close-range naval anti-aircraft weapon, has been ship-fitted for sea trials and firings against drone targets have started. *Seacat* launchers are to be fitted in the seven Leander-class and seven Tribal-class frigates. The first Tribal, H.M.S. *Ashanti*, is now undergoing trials.

MANNING THE PUMPS. The ship-side doors in the Union Castle Line's *Windsor Castle* (built by Harland & Wolff) are operated by a hydraulic system developed by Short Bros & Harland, and here a member of the crew operates the hydraulic pumps on one of the doors. Six such systems, comprising control unit, two actuators and hydraulic piping, are installed, each controlling one double ship-side door

H.M.S. *Dreadnought*, the navy's first nuclear submarine, was launched last year, and an order for a second ship has been placed. These hunter-killer submarines will be fitted with homing torpedoes, making them especially effective anti-submarine weapons. The *Wessex* anti-submarine helicopter, the first front-line squadron of which is to embark in H.M.S. *Ark Royal* later this year, will also carry homing torpedoes. Leander and Tribal-class frigates will carry the Westland P.531 light torpedo-carrying helicopter.

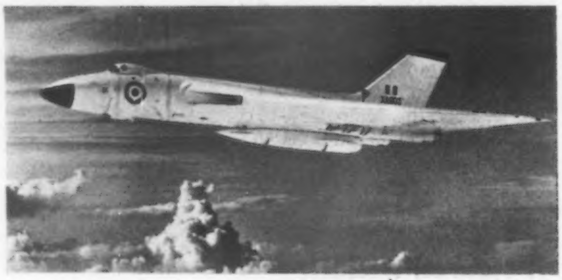
The aircraft carrier, H.M.S. *Eagle*, which is being modernized, is to have a new system for the handling of information and control of weapons. This makes use of the latest techniques of automation.

Royal Air Force

According to the *Memorandum by the Secretary of State for Air to accompany Air Estimates 1961–62*, Bomber Command now has *Vulcan 2*'s in service, and handling and maintenance

Seacat, the navy's close-range anti-aircraft guided missile, undergoing trials in H.M.S. *Decoy* (*Courtesy: Short Bros & Harland*)

Blue Steel, Bomber Command's stand-off bomb, falls freely from the carrier of a V-bomber before its own rocket motor takes over (*Courtesy: A. V. Roe*)



Blue Steel mounted beneath an Avro *Vulcan*

trials of *Blue Steel*, the stand-off (or powered) bomb will commence this year. 'Subject to the successful completion of its development programme, we plan to introduce *Skybolt*, the air-launched ballistic missile being developed in the United States, in the mid-1960's. Production weapons will be bought outright and will be carried by the *Vulcan 2*. They will be fitted with British warheads.' Bomber Command also handles the i.r.b.m. *Thor*, in conjunction with the Americans.

In Fighter Command, *Lightning* squadrons armed with the infra-red homing air-to-air weapon, *Firestreak*, are now in service, and the *Lightning Mk 3*, which will carry an improved air-to-air guided weapon has been ordered. The semi-active homing surface-to-air *Bloodhound 1* should be fully deployed during 1961–62. Regular practice firings on the Arberporth range, have demonstrated *Bloodhound*'s accuracy and high 'lethality'. An improved weapon, *Bloodhound 2*, is being ordered.

Fighter Command is working on a new high-performance radar system, which will include computers and data-handling equipment. This will be part of an integrated civil and military air traffic control organization.

The R.A.F. appears to be greatly interested in automatic data processing. One equipment, which will handle pay and records for civilians, will be operational this summer; another system—one of the largest integrated data-processing systems in the world—will control the provisioning and distribution of equipment; and a third will deal with the pay and records of airmen.

SPACE

Hawker Siddeley—Sereb proposals

A report, *Industry and space*, released by Hawker Siddeley Aviation in conjunction with the French organization, Société pour l'Etude et la Réalisation d'Engins Balistiques, Sereb for short, proposes an Anglo-French, or possibly European, approach to a space program. Hawker Siddeley's interest in the field, through the various aircraft firms which make up the Aviation Division, is, of course, well known; the Sereb organization is entrusted with the systems management of all ballistic missile development in France, and certain government controlled organizations are members of the company alongside many French aircraft concerns.

These two firms felt it would be to their mutual advantage to exchange opinions on the technical and industrial aspects of space problems, and to give broad outlines of a proposed joint effort. It was from these exchanges that the Report stemmed.

The cost of space

The Report surveys American achievements and gives an idea of the cost of these to the American taxpayer. During the four fiscal years 1958–61, the overall figure is $3200m made up as follows: research and infrastructure, $970m; technological development, $800m; scientific applications, $480m; military and 'man in space' programs, $950m. The American space effort constitutes 2–3% of the defence effort.

According to a table, analysing the total defence expenditure in relation to gross national product, the U.S. proportion is 10%, the British and French figure is 7%, while in other European countries it is 5%. Some further arithmetic leads the Report to suggest that over a four-year period Britain and France could together allocate $400m–$560m to space activities, and that all O.E.E.C. countries could provide between $800m and $1100m.

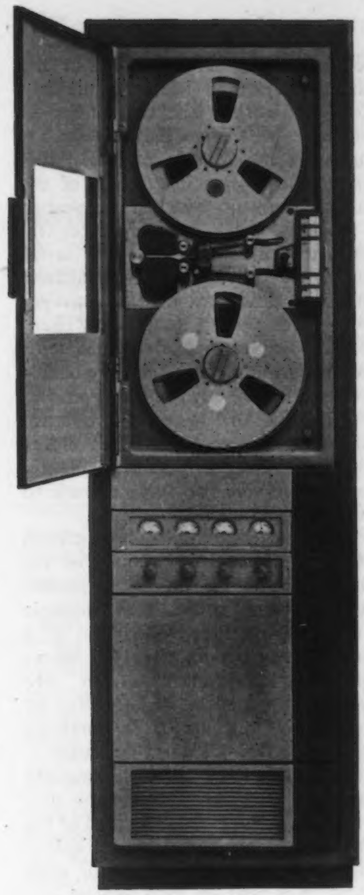
An $800m European program could be broken down into: research, equipment, data acquisition and handling, $300m; technological developments (including vehicles), $300m; specific space applications, $200m. An Anglo-French program — $400m over four years—would cost Britain $59m/year, and France $41m/year; co-operation between France, Britain, Germany, Italy and Benelux—$800m over four years—would cost Britain $60m/year, and France $44m/year. If the costs of an $800m program were shared by all European countries, Britain would spend $50m/year and France $30m/year.

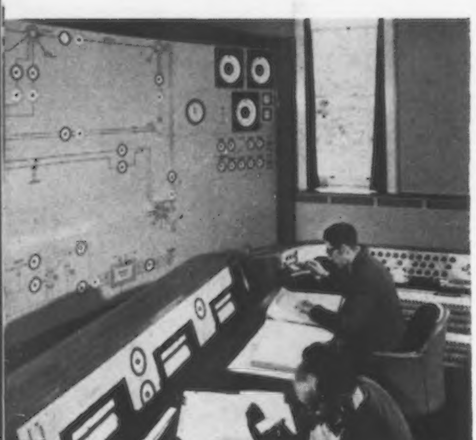
Communications satellites

The Report discusses two different types of communications satellite: a station-keeping and attitude-stabilized version having a transmitter incorporating a travelling wave tube and operating at 2000 Mc/s; and a lighter version having a thermionic valve or transistor transmitter and operating at around 500 Mc/s. The latter would not be mechanically stabilized but might have electronic stabilization by antenna selection.

Navigation satellites

A number of satellites, such that at least one would be sighted ten times a day, is proposed. Basically the idea is that the satellites should transmit a train of pulses which would be picked up by the observer and compared with his own (synchronous) train of pulses. The time lag between the two sets of pulses gives the observer his distance from the satellite; if he knows the position of the satellite at





GRID-CONTROL RECORDERS. The C.E.G.B.'s. Thames North Control Centre at Redbourne, Herts, one of seven area control centres (the others are in Birmingham, Bristol, East Grinstead, Leeds, Manchester, and Newcastle) which, under the supervision of a National Control Centre, now cover England and Wales. Honeywell electronic strip-chart recorders indicate the situation in the area. Two recorders—total generated output and system frequency—indicate load changes as they begin to occur, a third—'Net Area Transfer'—registers the import or export of power to other areas. The wall panel, a diagram of the area network, incorporates Cirscale (Record Electrical Co.) meters which show the power transfer on individual routes

the time, he can then determine his own position.

An anti-satellite system is also discussed.

The Hawker Siddeley-Sereb Report is most impressive and extremely informative. Whatever the political implications, and these are obviously formidable, the two companies deserve well of their respective communities for attempting to bring out into the open a problem with which Europe must sooner or later come to grips.

Venus probe's accuracy

The Russian automatic interplanetary station may well approach to within 60,000 miles of its target, Venus, a position it is expected to reach on 19 or 20 May. A multi-stage vehicle placed the heavy satellite in a planned orbit around the earth; then a second rocket took off from the satellite to place the automatic interplanetary station on course to Venus.

MOTOR CARS

Television at Standard-Triumph

A new automatic routing system which facilitates the inspection of car bodies, is now in operation at the Standard-Triumph Motor Company's Coventry works. The cars arrive on conveyor belts from the manufacturing areas into a new extension hall for further inspection. Each of the various types of vehicle is carried in a special skip which incorporates trip devices peculiar to the type it is intended to carry. These trips actuate routing mechanisms on the conveyor belt system which automatically channel the vehicles to their correct destinations in the area. There they undergo a series of stringent inspections, after which the 'passes' are automatically delivered to other floors while any rejects are diverted along a rectification line for further work to be done on them.

Thirteen Marconi closed-circuit television channels form part of the routing and inspection processes, cameras being installed at strategic points within the area. Within a central control room, five 14-in monitors provide pictures from five cameras mounted in various parts of the body-storage area, so enabling controllers to identify the various types of car body passing along the conveyor belts, and keeping the programming department informed of the current position. Details of the colour and other data are carried in code form on a card on each vehicle.

Any of the remaining eight cameras can be switched to the sixth picture monitor, so that a controller can watch the vehicles at all stages.

Television for Consett

Epsylon Industries have received a contract for a closed-circuit television system from the Consett Iron Co. Ltd. This is for the new Consett £14m four-high plate mill in County Durham. The order calls for nine camera channels, six monitors, control cubicles and ancillary equipment to the value of over £7000.

. . . and for process measurement

Increased interest is being shown in the use of closed-circuit television for monitoring process measurements, that is, as an alternative to conventional telemetering techniques. Recently, Pye equipment was demonstrated carrying out process monitoring, under the auspices of Woodall-Duckham Construction Co., at George Kent Ltd, Luton.

DATA HANDLING

Swedish order for Marconi

The Royal Swedish Air Board has placed a £1·7m contract with Marconi's Wireless Telegraph, for equipment for their air defence system. The Marconi equipment incorporates a high-speed computer which can solve a large number of interception problems simultaneously, and so enable the defence weapons to be brought into action. Both monochrome and colour television, together with automatic information-dissemination techniques, form part of the system.

NEWS BRIEFS

Machine translation conference in Moscow. It was announced that a machine able to memorize and classify information is to be built at the U.S.S.R. Academy of Science's Institute of Scientific Information. Vladimir Ivanov said that translating machines could not yet be used in practice in either the U.S.S.R. or the U.S.A.

L.D.E.P.'s American licensee: Lancashire Dynamo Electronic Products have a licence agreement with Emerson Electric Manufacturing Co., St Louis, Missouri, whereby the latter can manufacture L.D.E.P.'s industrial electronic control equipment on a royalty basis.

Rotron Controls Ltd has been set up by Elliott Bros, who have a two-thirds controlling interest, and The Rotron Controls Corp., Woodstock, New York, U.S.A. The company will manufacture Rotron flowmeters for positive and mass-flow measurements in the oil, gas, water and petrochemical fields.

Wayne Kerr have negotiated a licensing arrangement with Gertsch Products Inc, Los Angeles, U.S.A., whereby Wayne Kerr will make available Gertsch electronic instruments in the U.K., and so extend the range of Wayne Kerr measuring instruments using the transformer ratio arm technique.

Machine tool controls: Plessey have received an order for a further six (making eighteen in all) machine tool control systems from Alfred Herbert for the programmed control of Herbert DeVlieg Jigmils.

Automatic proportioning equipment (£60,000-worth), which eliminates manual weighing and feeding of ingredients to mixers, has been ordered from Simon Handling Engineers for use in the manufacture of rubber for footwear by Svit np. of Gottvaldov, Czechoslovakia.

Kent's Italian acquisition: 51% of the shares of the Tieghi company of Milan and Lenno have been acquired by George Kent, and a new company, Kent-Tieghi S.p.A., formed to hold the assets and goodwill of the Tieghi company. The intention is to expand Kent's activity within the Common Market. The new company's products include recorders and controllers (pneumatic) for flow, pressure and temperature, miniature pneumatic recorders and controllers, and force-balance transmitters.

Aircraft positions and heights, derived from an early-warning radar chain, are filtered and fed to indicators which incorporate automatic tracking devices. The latter extract positional information in the form of electronic pulses which are stored in a central memory or information bank. The stored data are fed to synthetic displays at positions manned by controllers who can thus see the category of information they require. The constitution or number of aircraft is obtained from a special display known as the 'magic carpet' where the radar picture shows the numerical composition of a formation. The targets displayed for analysis are presented automatically in a queue, which can be interrupted if a priority demand has to be dealt with.

All targets are labelled with a track number, which is also stored in the information bank together with such information as the availability of each category of weapon. Ancillary data, such as airfield readiness, or weather information, are displayed by a closed-circuit television system. A colour projector is used to present an overall picture of the air situation.

In operation, the Senior Control Executive decides on the appropriate action to be taken from the data at his disposal. The computer is fed with information about the enemy and the engaging fighters from the information bank, and calculates the interception path, taking into account pre-programmed information on the fighters' characteristics. Orders are transmitted automatically to defending aircraft.

Elliott's a.t.c. order

The Ministry of Aviation has placed a contract with Elliott Brothers (London) Ltd for experimental air traffic control equipment to be installed at the Air Traffic Control Experimental Unit. The equipment incorporates an Elliott 502 computer as its central data processing unit. The technical authority for the contract is to be the Ministry's Royal Radar Establishment, Malvern. The Elliott 502 is a medium-sized stored-program computer of high operating speed. It has been developed for use as part of on-line systems working in real time.

I.C.T. (Engineering) formed

International Computers and Tabulators are forming a new subsidiary, I.C.T. (Engineering) Ltd, 90% of whose nominal capital will be held by I.C.T., and the remaining 10% by G.E.C. The new subsidiary will take over certain responsibilities of I.C.T.'s Research and Design Division, and of the G.E.C. Computer Development Department at Coventry, although G.E.C. will continue to supply a substantial proportion of equipment to I.C.T. On the formation of the new company, I.C.T. will take over the majority interest in the joint I.C.T.–G.E.C. concern, Computer Developments Ltd.

CONVEYED TO RUSSIA. Auto-electronically controlled to a predetermined program, prepared and stored on punched tape, a Fisher and Ludlow Flowmaster conveyor system is to be exhibited at the British Trade Fair in Moscow. The required program is teleprinted into punched tape which is then fed into an electronic reader (E.M.I. Electronics) to provide electrical impulses for a control unit. The latter interprets the reader's instruction, operates the conveyor control mechanism, and checks that the instruction has been carried out before accepting the next instruction. In this way automatic marshalling, selection or sequencing can be pre-programmed

NEWS BRIEFS

Data loggers: Blackburn Electronics have received orders for a data logging equipment from Société de Traction et d'Electricité for a power station at Mol, near Brussels, where it will log 130 different temperatures, pressures etc., and from Rendel, Palmer and Tritton for a National Iranian Oil Co., project. The latter equipment will monitor temperatures at an oil-pumping station at Abadan.

Conveyor Construction and Engineering Co. Ltd is now part of the Teleflex Group so that the latter cover both light and heavy duty conveyors.

Telephone Cables Ltd is the new name for Southern United Telephone Cables (Chequers Lane, Dagenham, Essex) a company jointly owned by A.E.I. and Enfield Cables.

Astral Switchgear Ltd will move to Morecambe Rd, Ulverston, Lancs. (telephone: Ulverston 3333), from 31 March.

Controls Company of America (U.K.) Ltd has been set up as a subsidiary of the American organization's Canadian company. Initial assembly of flow controls for oil-fired boilers, heating equipment, domestic equipment and vending machines has begun at Woking, Surrey. The company's products are already marketed here under the names, AP Controls, Soreng Products and Redmond Motors.

Monorail installation, automatic and remotely controlled, which will enable remote selection of fissile material from any of seven bays and its delivery to any of twelve experimental stations in the Reactor Physics Hall at the Atomic Energy Establishment, Winfrith Heath, has been ordered from British Monorail by the U.K.A.E.A.

E.M.I. Electronics' telephone number will be Hayes 3888 from 24 April.

Vera — versatile experimental reactor assembly—a new U.K.A.E.A. reactor for physics experiments concerned with fast reactors, went critical at A.W.R.E., Aldermaston, on 22 February.

British Association of Cost Engineers: it is planned to form an independent British Association from the present British Group of the American Association of Cost Engineers. Details: T. B. Woods, 32 Spring Close, Sherborne St John, Basingstoke, Hants.

Livingston Laboratories Ltd will be at 31 Camden Road, London, N.W.1 (telephone, Gulliver 8501) from 4 April.

EXHIBITIONS

Engineering and electrical shows

Two important exhibitions of some interest to control engineers take place shortly, the Electrical Engineer's (A.S.E.E.) Exhibition which occurs at Earls Court, 21–25 March, and the Engineering, Marine, Welding, and Nuclear Energy Exhibition at Olympia from 20 April to 4 May. Both shows are worthy of the control engineer's interest, although neither is, of course, primarily concerned with control.

The A.S.E.E. affair is aimed at the electrical engineer and user of electrical equipment in the broadest sense, and covers both heavy and light equipment and rotating machines, switchgear, cables, lighting and so forth. However, a great deal of the equipment and ancilliaries to be shown will of necessity be concerned with controls and automatic devices.

The scope of the Engineering, Marine, Welding and Nuclear Energy Exhibition is, as the title implies, much wider, and auto-controls and devices will be much in evidence. If a choice between the two shows must be made, the Engineering exhibition is probably the more important from the control point of view, although attendance at both is recommended.

New for Control

A monthly review of system components and instruments

For further information, circle the appropriate number on the reply card facing page 162.

TRIGGER GENERATOR

high-voltage pulses

A portable instrument (M.640) by Winston Electronics has pulse-rate ranges of 10 to 100,000 pulse/s (free-running), and d.c. to 50,000 pulse/s (triggering operation). The output voltage is steplessly variable from 0–65 V, and output impedance is 500 Ω at 50% maximum output.

Output wave-form is a differentiated 'spike', with a rise time less than 0·15 μs even when feeding into a capacitance load. Pulse widths are 1, 10, 100 and 1000 μs, and the output-polarity may be either positive- or negative-going. External synchronization may be effected from signals down to 0·5 V peak, and external triggering from signals of 5V peak or greater; in either case, the signals must be of the same polarity as the required output.

Variable output

Circle **No 536** on reply card

ELECTROHYDRAULIC VALVE

single stage

Manufactured by Mitchell Hydraulics, a single-stage servo-valve is intended for use in sophisticated control systems; it is capable of control for a work demand of up to 10 h.p. (hydraulic).

Working stroke is ±0·030 in; maximum working pressure is 4500 lbf/in²; maximum flow is 4·1 gal/min, at a pressure drop of 1000 lbf/in². The input to the de Havilland-designed torque-motor is 4W maximum. Frequency response, at 25% amplitude, is ±3 dB up to 170 c/s.

Circle **No 537** on reply card

MOISTURE METER

permittivity principle

An instrument by Kappa is a frequency-sensitive device that measures, in arbitrary units, the permittivity of the contents of a removable test-cell. The permittivity of the sample depends upon its physical properties and moisture content, and changes in frequency due to changes in the latter are detected by a superheterodyne circuit. The frequency of the test circuit is nominally 9·85 Mc/s, which is sufficiently high to eliminate the effects of changes in conductivity.

A choice of three test-cell sizes (320, 1030, and 2700 cm³) ensures that the sample is representative of bulk. Mains supply required is 110 or 200–250 V, 40–60 c/s; power consumption is about 25 W.

Circle **No 538** on reply card

DIGITAL VOLTMETER

output for printer

A four-digit d.c. voltmeter by Solartron measures voltages from 100 μV to 1500 V in five ranges: input impedance is 10 MΩ for the three higher ranges, and 1 MΩ and 100 kΩ for the two lower ranges. Two additional ranges cover 0–100 V and 0–1000 V with input impedances of 100 MΩ.

Built-in Zener reference

The display is by optical projection, and the polarity of the input is indicated by the colour of the background (red or black); read-out time, irrespective of voltage, is 280 ms. Accuracy is ±0·1% of maximum reading on each normal range, the high-impedance ranges having an accuracy of ±0·5%. A 'check' position on the range switch permits zero setting: an internal Zener reference may be preset to its precise value, and checked against a built-in Weston cell. Two fifty-way sockets provide decimal coded information, and polarity and print-command signals suitable for feeding a Venner printer and additional display unit.

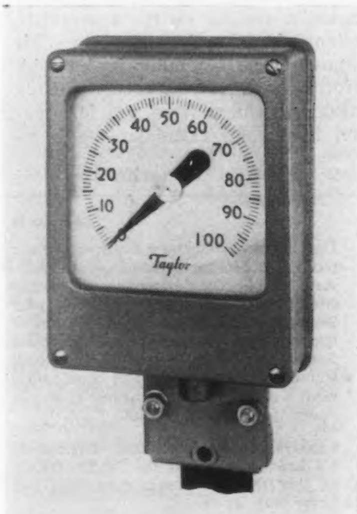
Circle **No 539** on reply card

PNEUMATIC TRANSMITTER

accurate, sensitive

Shortly to be available from Taylor Controls is an indicating pneumatic transmitter, the 210T, providing a 3–15-lbf/in² output. Working from a supply-pressure of 18–25 lbf/in², the instrument gives an output signal said to be within ½% of input signal, the dial indication being within 1% of actual value. Threshold sensitivity is 0·1% of input span, and the effect of a supply-pressure change from 18 to 25 lbf/in² is within 0·5% of output.

The dial is calibrated over 270°, giving an effective scale-length of over 11 in.



Clear indication

Ambient temperature limits are −20 to +150°F, a change from +50 to +150°F in case-temperature causing a change of ±½%. A non-indicating version, designated 211T, will also be available.

Circle **No 540** on reply card

VOLTMETER

high sensitivity and input impedance

The Halex (U.S.A.) model 301E Electrosensor voltmeter is a very sensitive unity-gain follower-amplifier with a d.c. following accuracy claimed to be 0·001%, and a

current sensitivity of 10^{-15}A. The effective input-impedance of this instrument is greater than 10^{17} MΩ, and input capacitance is less than 0·01 μμF.

The system consists of three unity-gain amplifiers completely surrounded by three distinct screens, the earth for the innermost amplifiers serving as the screen for the succeeding amplifiers. Each of the three screens is connected to one of the three insulated guard shields concentrically located around the centre input conductor, together with an external earth shield. The three guard shields are driven from the amplifiers in the instrument at voltages very nearly identical to the input signal on the centre conductor, so raising the effective input-impedance above that of the insulation and even above the free space surrounding the instrument. An output meter provides a display accurate to 1% and a switch selects eleven calibrated ranges with full-scale values from ±1 V to ±250 V d.c., or 500 V peak-to-peak for low-frequency a.c. Available from Scientific Furnishings, the drift of this instrument after warming up is quoted as 0·001% of full-scale voltage.

Circle **No 541** on reply card

PROCESS TIMER
ten time-ranges available

The type 7000 mk2 timer, by Rodene Electrical is made in a range including ten full-scale times from 15 s to 96 h full scale. The timer can be connected to start when a switch is closed, and to reset instantly when the switch is opened, or it can start on a pulse and reset automatically. It also provides a pulse at the end of the timed period which can lock a contactor or start a further timer.

Circle **No 542** on reply card

HEAVY DUTY BIN OUTLET
positive closure

A pneumatically-operated bin outlet is a heavy-duty clamshell shutter-gate which allows free flow when open, but has a positive closing action which completely stops the flow without risk of jamming even when handling large, irregularly shaped particles.

The pneumatic valves may be operated electrically or manually, and a series of gates can be arranged for automatic sequence-control. Six sizes cover a range of openings from 4½ × 4½ in to 18 × 18 in. The gate is constructed from mild steel, and is available from Lindars Automation. Sealing strips to prevent air leakage may be fitted. Circle **No 543** on reply card

PANEL METERS
withstand heavy overloads

Available from Painton are meters by Parker Instrument (U.S.A.) designed round a ceramic ring-magnet and a printed circuit. The movement is housed in steel shielding, and it is claimed that a bar magnet (200 oersted) applied directly to the case did not disturb the movement. Laboratory tests indicate that short overloads

Surface mounting

(about 0·1 s) of 20,000 times the instrument rating caused no harmful effects. Ranges manufactured so far cover 0–1 mA to 0–1 A, and 0–10 V to 0–500 V.

Circle **No 544** on reply card

OPTICAL CHARACTER-READER
up to 480 characters a second

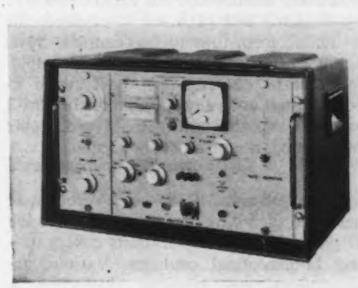
I.B.M.'s 1418 reads printed characters directly from documents at a speed of 480 per second. The document is flooded with light, and the reflexion is directed *via* a lens to a scanning disk. The image so formed is compared with characters (and certain standard symbols) stored in the unit's memory, and on agreement the appropriate character is printed. Delivery of this device will begin in 1962.

Circle **No 545** on reply card

TRANSISTOR ANALYSER
simple to operate

The parameters of both *p-n-p* and *n-p-n* transistors can be measured with this Microcell analyser. These include, for transistors, amplification factor, cut-off frequency, collector leakage-current and collector turn-over voltage (grounded emitter configuration), and turn-over voltage and collector current of diodes.

Amplification factor is measured by a differential-input wide-band valve-voltmeter



Accurate, stable

with a response within ±1·5 dB over its entire range. The associated Wien bridge oscillator, covering 1 kc/s to 10 Mc/s, is amplitude-stabilized to within ±1·5 dB. Collector supplies are 0–100 V at 30 mA and 0–10V at 3A, and the collector-current meter covers 30μA to 3A in six ranges. Turn-over-voltage range is 0–100 V, with internal current limitation to 5 mA. Overall accuracy is 3%.

Circle **No 546** on reply card

SQUARE-WAVE GENERATOR
wide frequency-range

A square-wave generator, Feedbacks' SW98, generates square-wave driving signals for repetitive analogues. A square wave at mains frequency is provided, and the unit will generate square waves from externally-applied sine waves over the range 50 c/s to 10 kc/s. Rise time is about 2 μs at any frequency, and the mark-space ratio may be adjusted exactly to 1:1. Minimum

Incorporates calibration oscillator

input signal is 2V peak, and the output is continuously variable to a maximum of 50V peak-to-peak. Maximum current output is ± 5mA peak-to-peak.

A tuned circuit is incorporated to generate a calibration oscillation at 2·5 kc/s, for time measurement on an oscilloscope trace. The oscillation train may be switched to occur during either the positive or negative half of the square wave.

Circle **No 547** on reply card

QUICK LOOKS

Epitaxial transistor. Texas Instruments' silicon transistor manufactured by the epitaxial process is claimed to have a switching speed twice as fast as any other silicon transistor. The XB26 will give useful amplification up to 200 Mc/s, with a total switching time (under saturated conditions) of 30 mμs. Circle **No 548** on reply card

Indicator strips, carrying twelve sockets with either ½- or ¾-in centres, are available from Thorn Electrical. Lamps may be supplied for 6-, 12-, or 28-V operation, at 35–45 mA: life expectancy of these is 3000–5000 hours.

Circle **No 549** on reply card

Power supply. The 115D power supply, designed primarily for use with the Uni-

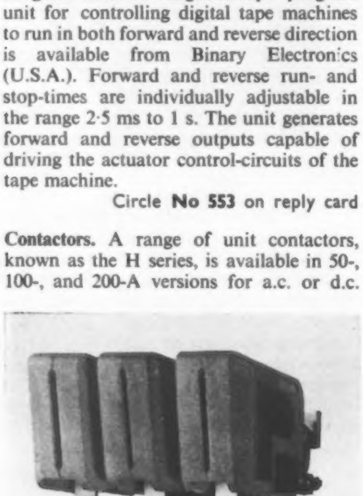
cam SP.500 spectrophotometer, is available from Labgear. Output voltages are 6 V d.c. at 6 A, 6 V d.c. at 100 mA, and 2 V d.c. at 100 mA. Stability factor is given as 1000:1 for input variations of −15 to +20%. Ripple and noise are approximately 3 mV peak-to-peak; mains input required is 90–130 V or 220–240 V, 50 to 60 c/s.
Circle **No 550** on reply card

Gas controls. Honeywell's gas control units have gas governor, pilot safeguard and main gas control mounted in a single unit. Three sizes are available for controlling appliances from 0–30,000 Btu/h, 30–65,000 Btu/h, and 0–300,000 Btu/h. A feature of all three units is that they permit the use of sensitive low-voltage room thermostats to control the appliance directly. Circle **No 551** on reply card

Photocell. Developed by Mullard for infra-red applications, the ORP13 photocell is a very sensitive device with a spectral range from visible to about 5·4 μm. Its sensitivity to monochromatic incident radiation is 15mV/μW. To limit noise, the cell is attached to its own Dewar flask, and is cooled by liquid nitrogen to −196°C.
Circle **No 552** on reply card

Program unit. A magnetic-tape program unit for controlling digital tape machines to run in both forward and reverse direction is available from Binary Electronics (U.S.A.). Forward and reverse run- and stop-times are individually adjustable in the range 2·5 ms to 1 s. The unit generates forward and reverse outputs capable of driving the actuator control-circuits of the tape machine.
Circle **No 553** on reply card

Contactors. A range of unit contactors, known as the H series, is available in 50-, 100-, and 200-A versions for a.c. or d.c.



working. Each version may be supplied as a single- or multi-pole unit. Additional poles may be added (within each version) to a single-pole unit, without changing the coil. Rated to B.S.S.775 (A4 or D4) and having full C.S.A. approval, they are short circuit tested at 31 MVA against their respective h.r.c. fuse ratings. Made by Dewhurst and Partner, these units are said to be exceptionally quiet in operation.
Circle **No 554** on reply card

Photo-conductive cells. Cadmium sulphide cells made by National Semiconductors (Canada) are available from Hird-Brown. The range covers power dissipations from 0·3 W to over 2·0 W.
Circle **No 555** on reply card

Flow indicator. An indicator by Suba Hydraulics shows approximate proportion of full flow in horizontal or vertical lines at

pressures up to 100 lbf/in². Six sizes fit pipes from $\frac{3}{8}$ to $2\frac{1}{2}$ in diameter, inlets and outlets being threaded B.S.P. A fractional scale can be fitted if required.
Circle **No 556** on reply card

Valves. A range of hand-operated valves by Rollason Aerocessories is recommended for use in high-vacuum installations. Four sizes cover 100–200 lbf/in², and the valve is constructed so that the spindle operates *via* a thrust-pad pressing on the diaphragm to give leak-proof operation.
Circle **No 557** on reply card

Electronic multiplexer. An expandable unit by Packard Bell (U.S.A.) is available for switching from four to 64 channels. Basic settling time is 20 μs, and the full complement of 64 channels can be scanned in 50 μs. Input and output limits of the EM-3 are ±10 V; the unit will drive a stable load impedance of 25 kΩ or greater.
Circle **No 558** on reply card

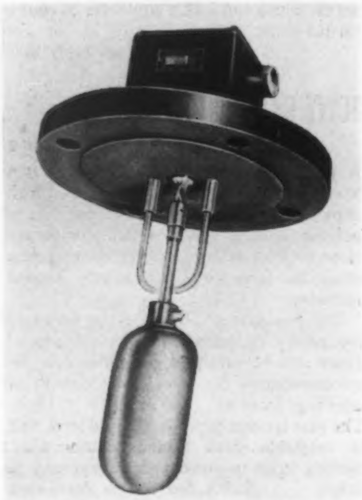
Counter sub-units. Built on 'Veroboard' bases 4·8 × 5·4 in, Vero Electronics range of plug-in Dekatron sub-units covers uni- and bi-directional counters. Various arrangements are possible, including a positive 35-V step-output at a maximum repetition rate of 400 c/s (type BDS400). Also available are transistor input-waveform shaping-units.
Circle **No 559** on reply card

Stabilized supply. A unit by Philbrick (U.S.A.), using solid-state circuitry, provides two outputs: +15 V d.c. and −15 d.c., each at 200 mA. Prolonged short-

circuit does not harm the supply, as short-circuit current is internally limited to less than full-load current. Line and load regulation is under 0·01%, and ripple is less than 0·5 mV. Designated model 6033, the unit requires a mains supply of 115 V a.c. Circle **No 560** on reply card

Micro-miniature lamp. Measuring 0·055 in diameter by 0·175 in length, Thorn Electrical Industries' 'Mite-t-lite' will operate between 1·0 and 1·5V, with a current consumption of about 30 mA at 1·3 V d.c. Working at that voltage, life expectancy is approximately 2000 h. Owing to the low thermal inertia of the filament (forty turns of tungsten wire 0·00025 in diameter), light output will follow voltage impulses up to 100 pulse/s.
Circle **No 561** on reply card

Liquid-level alarm. An addition to A.E.I.'s range of packless flexible-shaft level controllers operates by sensing changes of buoyancy in the displacer. Any movement of the displacer is transmitted to a micro-

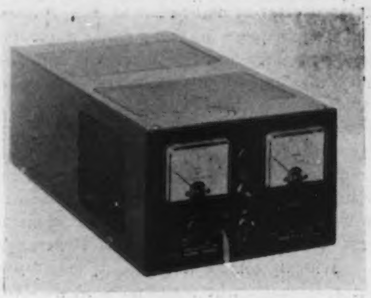


switch by a stiff tongue within the flexible shaft. Operating temperature range is +65 to +500°F, and the micro-switch is operated by a level-change of ½ in at unity specific gravity.
Circle **No 562** on reply card

Differential refractometer. An instrument by Waters Associates (U.S.A.) measures changes in refractive index as small as 5 × 10^{-7} units. Available in the U.K. from

Scientific Furnishings, the unit uses digital indication. Circle **No 563** on reply card

Power supply. Available from Invar Electronics (U.S.A.), the TPA-36-18 provides either 0–18 V d.c. at 3 A or 0–36 V d.c. at



1·5 A. On either range, line regulation is 10 mV maximum, and load regulation is 5 mV maximum; ripple is not greater than 0·3 mV. These transistor units are designed for mounting on 5¼ × 19-in relay rack panels.
Circle **No 564** on reply card

Radiation monitors. Intended for accurate monitoring of gamma radiation, A.E.I.'s two monitors use an electrometer valve as a cathode follower. The GM1 is a linear instrument with four ranges from 0–125 mr/h to 0–1000 mr/h; the GM2 has a logarithmically calibrated range of 0·1 mr/h to 10 mr/h covered in five decades. Relative accuracy is ±3% f.s.d. and seven-day stability is better than 2% for both instruments.
Circle **No 565** on reply card

Linear measurement. An instrument by Reilly Engineering is claimed to measure length extraordinarily accurately. The system consists of a set of identical slip-gauges mounted on a shaft and connected to an alternating supply. When a further ring (concentric to the slip-gauges) moves along the shaft the voltage induced is an indication of its position. Accuracy in 1 in, for example, is given as ±0·0003 in.
Circle **No 566** on reply card

Wire-wound potentiometer. A potentiometer by Painton is sealed against humidity and will operate at temperatures up to 175°C. Measuring 1·25 in long, it has a 22-turn screwdriver adjustment which is self-locking and vibration-proof. Resistance values up to 100 kΩ are available, and power dissipation is 1 W at 70°C and 0·5 W at 125°C.
Circle **No 567** on reply card

Ferrite storage core. The XCWT 508-10 core, made by Ampex (U.S.A.), will operate over a temperature range from −55 to +100°C. Intended for coincident current memory operation, this 0·05-in core is now available in experimental quantities. Circle **No 568** on reply card

Reducing valve. A 3-in butterfly valve, intended for use in jet aircraft, will control air at temperatures up to 400°C and input pressures up to 200 lbf/in². Air-flow limit

for average pressure-drop is 8lb/s, and leakage when the valve is closed is below 1 lb/min. Made by Hymatic, the PAS.217 gives a downstream pressure of 25–35 lbf/in² for the full range of up-stream pressures. Circle **No 569** on reply card

PUBLICATIONS RECEIVED

Kinetics, Equilibria and Performance of High Temperature Systems *by* **Gilbert S. Bahn** *and* **Edward E. Zukoski.** *Butterworths Scientific Publications Ltd. 1960. 255 pp. £4.* ★ **570**

Europe—A great idea materializes. *Publications Department of the European Communities. 1960. 60 pp.* ★ **571**

Transistors in Experimental Work *by* **F. M. Russell.** *U.K.A.E.A. 1960. 33 pp. 6s.* ★ **572**

A History of Flow Measurement by Pressure-Difference Devices. *George Kent Ltd. 1960. 52 pp. 10s.* ★ **573**

Glossary of terms used in Automatic Controlling and Regulating Systems. Section 2: Process control. *British Standards Institution. 1960. 22 pp. 6s.* ★ **574**

7 GeV Proton Synchroton (Nimrod) Power Supply and Control Circuits for Magnet Models AC1, AC2 and AC3 *by* **A. J. Holt.** *A.E.R.E. Harwell. 1960. 14 pp. 2s. 6d.* ★ **575**

The Evolution of Instrumentation *by* **Arthur Porter.** *Ultra Anniversary Lecture. 1960. 12 pp.* ★ **576**

The Progress of the Common Market and its effects on the United Kingdom. *The Federal Trust for Education and Research. 1960. 74 pp. 10s. 6d.* ★ **577**

Bulletin of Special Courses in Higher Technology, 1960-61, Part II: Spring & Summer Terms. *London and Home Counties Regional Advisory Council for Technological Education. 1960. 78 pp. 3s. 6d.* ★ **578**

British Aviation. *Business Dictionaries Ltd. 1960. 222 pp. £1.* ★ **579**

Dictionary of Automatic Control *by* **Robert J. Bibbero.** *Reinhold Publishing Corp. 1960. 282 pp. £2 5s.* ★ **580**

Fundamentals of Signal Theory *by* **John L. Stewart.** *McGraw Hill Publishing Co. 1960. 346 pp. £3 10s.* ★ **581**

Translation from Russian for Scientists *by* **C. R. Buxton** *and* **H. Sheldon Jackson.** *Blackie & Son Ltd. 1960. 299 pp. £1 10s.* ★ **582**

Programming for Digital Computers *by* **J. F. Davison.** *Business Publications Ltd. 1961. 175 pp. £1 15s.* ★ **583**

Proceedings of the Symposium on Recent Mechanical Engineering Developments in Automatic Control. *London 5th–7th January, 1960. The Institution of Mechanical Engineers. 1960. 227 pp.* ★ **584**

Rectifiers. Medium power silicon-rectifier stacks by International Rectifiers are listed in their bulletin SR2007. ★ **585**

Racks, cabinets, chassis, etc., based mainly on standard 19-in modules, are listed in a recent brochure from Linvar. ★ **586**

Computer system. An illustrated booklet (list DC.4) from Ferranti contains a detailed description of their Pegasus 2 computer system. ★ **587**

Compass. Sperry's Gyrosin compass (Type C.L. 6) is described in a brief leaflet. ★ **588**

Flow measurement. Fischer and Porters' 165-page manual contains full details of their electromagnetic flowmeter range, and also lists secondary indicators, recorders, integrators, etc. ★ **589**

Machine-tool control. A.E.I.'s Numeritrol system, for controlling in two or three dimensions using ½-in magnetic tape is described in publication 4103-1. ★ **590**

'pH meters by E.I.L.' is the title of their recent illustrated brochure. ★ **591**

Cam pick-offs. A recent leaflet from Servo Consultants describes their series 400 transistor pick-offs. ★ **592**

Industrial ovens and furnaces made by A.E.W. are the subject of their illustrated catalogue. ★ **593**

Liquid level controls are listed in data sheet LR (issue 4) from Elcontrol. ★ **594**

Industrial radiography. A 16-page booklet explains the facilities available at the Kodak School of Industrial and Engineering Radiography. ★ **595**

Low-voltage transformers, type C50; weather- and dust-proof versions are shown in a leaflet from Donovan Electrical. ★ **596**

Stabilizeu d.c. supply units incorporating electrolytic capacitors are the subject of list No 1453 from Fraser, Speller Transformers. ★ **597**

Closed-circuit television. Beulah's D.800 camera is the subject of their recent leaflet. ★ **598**

Control gear for electric pump-motors is illustrated in a brochure from Dewhurst and Partner. ★ **599**

Nuts. An 84-page manual from Simmonds Aerocessories describes their wide range of spring-steel fastenings. ★ **600**

★ **Circle the relevant number on the reply card facing page 162 for further information**

Book Reviews

Systems

Principles of Control Systems Engineering *by* **Vincent del Toro** *and* **Sydney R. Parker.** *McGraw Hill Publishing Co Ltd.* 1960. 686 *pp. £5 12s. 6d.*

From the title of this book it is concerned with the 'principles' of control engineering, which poses the problem of what subiect matter is considered appropriate under this heading. There are many books on the principles of control engineerng and these have established a general pattern of content and balance of emphasis. In view of the length of this book, some 630 pages of text, it is somewhat unbalanced in emphasis.

The normal initial features, differential equations, Laplace transformations, time and frequency domain analysis, are presented in great detail occupying rather more than half the book. The remaining portion is concerned with root-locus methods, synthesis of *RC* networks, analogue and digital computers, and a final chapter on self-adaptive systems. There is, however, no consideration of carrier or sampled-data systems, statistical principles and applications, or simple non-linear analysis, and from the preface these are regarded as appropriate to more advanced texts. As a result, in the chapter on self-adaptive systems, convolution integrals and correlation functions appear, although no background information on these is available in the book.

The presentation is detailed and comprehensive, particularly in the first half. Many examples are considered, and some emphasis is placed on the design problem of meeting a required performance specification with given major components of a system. On computers, analogue techniques are introduced with numerical examples, and a simple program for a digital computer is developed which well illustrates the essential ideas. The chapter on self-adaptive systems is concerned with general principles, together with some detailed analysis, of systems which maintain a specified overall performance against parameter variations. Examples are given illustrating both analogue and digital control techniques, but self-optimizing systems or 'hill-climbers' are not treated.

To sum up; the book presents the major basic features of linear system analysis, though these are treated in considerable detail for a 'principles' book, and topics which might be expected to rate inclusion before self-adaptive systems are omitted. The book is excellently produced, with copious diagrams, and at the end of each chapter is a selection of problems, the solutions to the majority being available.

P. F. BLACKMAN

Programming

Annual Review in Automatic Programming *edited by* **Richard Goodman.** *Pergamon Press. 1960. 300 pp. £3 3s.*

'Automatic Programming' is the term used to cover various autocodes and interpretive and compiling schemes, devised to free the programmer from the restrictions implied by the logical structure of the computer he is using. Each of the many different computers available at present has had one or more of these schemes developed for it, and a growing need has been felt for some attempt at unification. The book consists of a collection of papers on this topic read at a conference in Brighton in April 1959, and two appended supplementary papers from other sources.

From the nature of the collection there is inevitably a certain variation in quality, and some of the schemes have been given only a very brief description. The chief value of the book is undoubtedly that it does bring these often very different schemes together under one cover, so that they can be easily compared. The inclusion of an early description of Algol, the only major attempt at unification to date, rounds the book off neatly. Turing's papers on computable numbers, which imply that any computer satisfying certain minimal conditions can be made to simulate any other computer, are also included, to provide a theoretical background.

The book as a whole implicitly assumes some knowledge of programming in the reader. To anyone with this knowledge it provides an admirable survey of current progress in this field, as well as suggesting possible future developments. The control engineer will find some interesting material in a paper on the automatic control of machine tools. Generally, however, the book is obviously aimed at practising programmers, in particular mathematicians, who may find some implied criticisms of current mathematical notation worthy of study.

The presentation throughout is both clear and attractive, and there are commendably few typographical errors, even in the most complicated mathematical expressions. There is a brief but representative bibliography.

T. H. GOSSLING

Memory

The Cathode Ray Tube Memory of the High Speed Electronic Computer of the U.S.S.R. Academy of Sciences *by* **V. N. Lant** *and* **L. A. Lynbovich.** *Pergamon Press Ltd. 1960. 90 pp £1 15s.*

This volume is a collection of papers which describes the internal memory based on cathode-ray tubes of the type used in the U.S.S.R. high-speed computer. The design and construction of the memory unit was carried out by a group of engineers on the initiative and under the direct leadership of Academician S. A. Lebedev, the chief constructor of the high-speed computer. The present book by two members of the group, gives a complete description of the system, proceeding from a statement of requirements and schematic diagrams of the memory to the final chapter on operational experience and conclusions. It gives the memory system in considerable detail, explaining the construction and physical principles of the potentialoscope, with details of the circuit used, including many photographs and diagrams to illustrate the design and construction.

The standard of the printing is relatively low, but it is understood that non-letterpress setting and photolithography has been used for speed, to ensure the prompt availability of this material to the technical reading public.

The work should be invaluable to western scientists, not only for the contents, but also as an indication of current Russian thought and progress in this field of high-speed electronic computers.

DENIS TAYLOR

Venturis

A History of Flow Measurement by Pressure-difference Devices. *George Kent Ltd. 1960. 52 pp. 10s.*

Most appropriately, a portrait of Giovanni Battista Venturi adorns the front cover of this booklet, which contains the collected series of articles published in *The Instrument Engineer* over the years 1952-59. Beginning with biographical notes on Venturi himself (who flourished in 1746-1822) and Herschel, the story continues with accounts of notable Venturi-meter installations and historical development up to more recent low-loss devices. Appendices give background data and theory.

The booklet is well produced, though the size and binding make it unsuitable for the reference book shelf where one might like to keep it. Ten shillings is a rather forbidding price.

R. M. LAMBERT